TESTING A BIOSONAR ACTIVATED DETERRENT DEVICE: THE INTERACTIVE PINGER

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SUMMARY

Multiple studies have shown that bycatch in gillnets fisheries is above sustainable levels for several harbour porpoise populations in European waters. Different mitigation methods have been tested and especially acoustic alarms (pingers) have proven efficient. The present study tested the effect of a single interactive pinger (prototype), on the behaviour of wild harbour porpoises. This type of pinger only emits a displacement sound when triggered by porpoise biosonar. This was done by obtaining the overall movement pattern, calculating the median of the minimum approach distance to the pinger, and comparing several parameters between the dives where a displacement sound was emitted (S-dives) with dives during *Baseline* conditions (B-dives). The observations were conducted on free-ranging harbour porpoises at Fyns Hoved (Denmark), on three separate occasions in 2002 and 2003. The interactive pinger was deployed from a small boat at a depth of approximately 2.4m. Porpoise movements around the device were recorded with a digital theodolite placed on a 20m high cliff with a good view of the study area. Only data within a 400m range of the pinger was analysed (based on the porpoises' theoretical acoustic detection range of the pinger and the precision of tracking), and in 17 of the 57 tracks obtained, a displacement sound was emitted. The S-dives were significantly different from B-dives in 3 out of 4 parameters tested, and the effect disappeared in the subsequent or second dive after the S-dive. The median of the minimum approach distance was 114m for the active pinger and 72m for the inactive pinger. In conclusion, the interactive pinger was effective in displacing the harbour porpoises and only seemed to have a short-term effect on their behaviour. The sound emission from the interactive pinger was equivalent to approximately 1-3% of the emission from standard beacon-mode pingers.

Key words: Mitigation, By-catch, Acoustic alarm, Harbour porpoise, *Phocoena phocoena*

Short title: TESTING AN INTERACTIVE PINGER

INTRODUCTION

The harbour porpoise, *Phocoena phocoena* (G. Cuvier), is one of the most abundant and widespread cetacean species in the North Atlantic, and it is the most common cetacean in the Danish waters.

In 1994 an extensive survey (SCANS – Small Cetacean Abundance in the North Sea), using shipboard and aerial line transect sampling, was conducted in the North Sea and adjacent waters. Based on this survey the abundance of harbour porpoises was estimated to 341.366 individuals. (Hammond *et al.*, 2002). In spite of this relatively high abundance estimate, concerns have been raised about the sustainability of the populations of the North Sea and adjacent waters (Donovan and Bjørge, 1995; Koschinski, 2002; Stenson, 2003). Especially the porpoises in the Baltic Sea, which is considered to be a discrete subpopulation (IWC, 2000), seem to have been declining drastically (ASCOBANS, 2003). Several anthropogenic factors have been identified as affecting harbour porpoise populations, but the most serious impact on the abundance of porpoises is considered to stem from direct mortality through high levels of incidental catches in fishing gear, and especially gillnets (Tregenza *et al.*, 1997; Vinther, 1999; Vinther and Larsen, 2004).

In 1994 the governments in the region around the Baltic and the North Sea accepted that fishing operations pose a potential threat to small cetaceans and especially harbour porpoises. A conservation and management plan for the cetaceans in the area was therefore implemented under the “Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas”

(ASCOBANS, 1997). According to this agreement the harbour porpoise populations should be kept at or restored to 80% of the carrying capacity. In short term, this means that yearly removals, including by-catch, must not exceed 1,7% of the population size (ASCOBANS, 2000). Harwood et al. (1999) estimated the by-catch rate of porpoises in the North Sea and found that it exceeded the mortality limit, and the current by-catch in the Baltic Sea also seems to prevent the population from recovering to 80% of the carrying capacity (Berggren *et al.*, 2002).

In order to reduce the by-catch and comply with the ASCOBANS agreement, multiple mitigation methods have been tested and their effects evaluated. Pingers especially have shown promising results, and are mandatory in several types of commercial fisheries of different regions (Larsen *et al.*, 2002; Barlow and Cameron, 2003). From June 2005 new EU regulations introduce mandatory use of pingers in additional gillnet fisheries in the North Sea and selective areas of the Baltic Sea for boats > 12m in overall length (Anonymous, 2004).

An ideal acoustic alarm has to meet a series of requirements. The most important is obviously that it should reduce the by-catch of porpoises, and do so without habituation, which could reduce the efficiency in the long run. In addition, this should happen without the side effects of excluding the porpoises from excessively large areas, disturbing other marine mammals or lowering the catch rate of the target species for the fishery.

The concept of the interactive pinger makes it possible to emit displacement sounds only when needed, *i.e.* when triggered by the sonar of a harbour porpoise. As a consequence, less noise will be emitted into the environment compared to beacon mode pingers, where displacement sounds are emitted continuously with fixed or variable intervals. This reduced emission will cause less disturbance to the marine environment and should lower the risk of excluding the porpoises from an excessively large area.

Also, a porpoise approaching a beacon mode pinger from a distance experiences a progressive increase in the received sound pressure level from the successive emission of displacement sounds. In contrast, a porpoise triggering an interactive pinger will experience a sudden onset of sound emission at a relatively close range. Since the emissions will be more infrequent and unpredictable for both the porpoise that triggers the pinger and other porpoises in the area, the resulting emission pattern will most likely lower the risk of habituation compared to beacon mode pingers.

Prior to this study a prototype of the interactive pinger was tested on three porpoises held in an open-designed enclosure at the Fjord&Baelt (Kerteminde, DK). The prototype proved to be efficient in displacing the porpoises. Also, the porpoises were reluctant to approach the transducer after the test session, most likely because the interactive mode made it difficult to for see the sound emission (Lockyer *et al.*, 2001). The next step was to test the concept on wild naïve harbour porpoises, which is the main objective of this project. We did this in a controlled experiment by comparing the movements of wild porpoises during experimental treatment and control situations.

MATERIALS AND METHODS

The experiment was conducted from August 10th – September 7th 2002, May 5th – 22nd 2003 and June 23rd – July 1st 2003 in Kattegat at the northwest tip of the peninsula Fyns Hoved in Denmark (Fig. 1). Here, a steep shoreline cliff approximately 20 meters high offers unobstructed view of an area where porpoises are abundant. The water depth in the area of interest is less than 10m. The area is used for recreational sailing as well as fishing, transit of fishing vessels and at distance of several km also cargo shipping.

A circular experimental area with a radius of 150m was established and centred at a study boat, which was anchored approximately at the same distance from the shoreline (Fig. 1). Three buoys marked the outline of the area, and a fourth buoy (Pinger buoy: **PB**) in the centre was used as moorings for the study boat (acoustic platform (see below)). All buoy locations were initially determined by use of GPS (Global Positioning System).

Study design

The interactive pinger was deployed from the small study boat. The boat arrived at the site in the morning and returned to the harbour in the evening, when light and/or weather conditions prevented further observations. The positions and timing of porpoise movements around the pinger (constituting tracks) were recorded with a digital theodolite from an observation point at the top of the cliff. Observations were conducted during daytime hours whenever the sea state was two or less, and if it was not raining heavily.

Three situations were compared during this study: *no pinger*, a control, where no equipment is in place; *Baseline*, the pinger is present but inactive and *Active pinger*, a displacement sound is emitted each time the interactive pinger is triggered by a porpoise sonar click. The porpoise tracks obtained during these three situations are referred to as *no pinger* tracks, *Baseline* tracks and *Active* tracks, respectively.

The specific parameters used to assess the effect of the interactive pinger on the diving behaviour of the porpoises were: a) General movement patterns, based on 2D plots of the surfacings, b) Distance between the porpoise surfacings and the pinger, c) Length of the dives, d) Duration of the dives and e) Apparent swimming speed. Point b) was specifically used to determine whether the porpoises swam away from the pinger when a displacement sound was emitted. The distance between the porpoise surfacings and the pinger was also used to calculate the median of the minimum approach distances and to compare this between *Baseline* and *Active* tracks. Point c), d) and e) were used to estimate the effect of the pinger sound emission on specific dives in a track.

Test strategy and period

Each treatment or control was implemented for a predefined time frame, referred to as a block. The order of treatment and control blocks was determined from a randomisation table. The experiment was "blind" in the sense that the observers tracking the porpoises did not know whether it was a treatment or control situation.

The definition and order of blocks changed prior to the last test period (Table 1).

First strategy

During the 1st and 2nd test period a block was defined as the time from a porpoise or a group of porpoises entered the experimental area, i.e. within a radius of 150 m from the acoustic platform, and until it/they had left it again. In situations were more than one group of porpoises entered the experimental area at the same time, the block continued until all porpoises had left the area.

During the first two test periods, passing outboard motor boats were able to trigger the pinger, as was a frequently occurring single click noise in the water (origin undetermined). Therefore displacement sounds were emitted much more often than intended, and at unexpected times. An operator in the boat reduced this false triggering by manually disconnecting the displacement sound device, until a block was initiated.

Second strategy

In the 3rd test period only the treatment, *Active* pinger, was applied. This treatment was used exclusively due to the low number of tracks obtained for this treatment during the two previous test periods. In this last test period the software was changed in order to eliminate false triggering. Now, 2 clicks above the threshold trig level and within one second were required for the device to be triggered, rather than just one click as during the 1st and 2nd test period. This made it possible to have the displacement sound device connected at all times, although still with a considerable amount of false alarms, mainly caused by outboard motor boats.

Workstations

The observation team consisted of two workstations: the tracking station and the acoustic platform.

The purpose of the tracking station was to track the movements of porpoises in the area by recording a horizontal and vertical angle to all surfacings. Joining subsequent positions of the surfacings formed the tracks.

The tracking station consisted of a digital theodolite placed on a tripod. The station was situated on the top of the cliff approximately in line with the **PB** and **BW** buoys (Fig. 1). The position and height over the ground of the theodolite was the same during all observations. In addition, the horizontal angles recorded by the theodolite were calibrated before each observation session by the use of a reference point with a known compass bearing. The sea level changes were recorded at regular intervals and taken into account in all calculations of distances. The position of the theodolite, approximately 20m above sea level, allowed a resolution in distances computed from the theodolite measurements of approximately 2% of the distance at 150m and 5% of the distance at 300m.1)

The observers always tracked the porpoise spotted closest to the pinger and each track continued until the porpoise was either out of sight or another porpoise was spotted closer to the pinger (change of focal animal).

The acoustic platform was based in the boat moored to the **PB** buoy. From this location the operator controlled the pinger, and used an acoustic monitoring system to listen for and record porpoise clicks. The prototype of the pinger consisted of two transducer units and a monitoring/controlling set-up (Fig. 2).

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1) The increase in error percentage with distance was related to the sheltering effect of the hill. With a southern or eastern direction of the wind, a progressive increase in sea state with distance from the shoreline could be observed. The accuracy of tracking was under these circumstances affected not only by the direct limitations due to distance (vertical angle accuracy), but also by the differing sea states.

A modified AQUA*mark* 100 unit (**AS**) transmitted the eight standard AQUAmark 100 squeep sounds. Squeep sound is the common designation chosen for all the displacement sounds. These sounds were all 256ms long, broadband (20-150 kHz) and multi-harmonic. Six of the squeeps were up- and/or down-sweeps and two were non-modulated square wave tones. The source level of the signals was approximately 154 dB p-p re 1μPa @ 1m. The output was pseudo-randomly changed between these eight sounds. A 13mm spherical hydrophone recorded the porpoise echolocation signals as well as the **AS** transmissions. The hydrophone was mounted next to the **AS** and this combined system was deployed over the side of the boat to approximately 2.4m below the surface (Fig. 2).

The incoming signal of the hydrophone was amplified 46dB before entering a porpoise envelope click detector (Fig. 3). A high pass filter in the click detector eliminated most of the boat and wave action noise, and allowed for the detection of porpoise echolocation signals in the frequency band 100-150 kHz.

The signal from the click detector was sent through a custom designed Trigger box. If the input signal reached a pre-set trigger level, corresponding to a received level of 137 dB p-p re 1μPa, a digital signal was sent from the trigger box via the parallel port to a laptop computer. This trigger level would in theory allow the porpoises to trigger the device at a distance of approximately 55m (based on: SL = 172 dB p-p re 1μPa @ 1m (Au *et al.*, 1999), centre frequency = 130 kHz (Møhl and Andersen, 1973), and transmission loss = mix of spherical and cylindrical spreading plus absorption). The computer ran a custom made software controlling and recording the output of the **AS** device.

A speaker, connected to the click detector, allowed the boat operator to monitor the underwater acoustic events including the **AS** transducer emissions.

A mini-disc recorder was connected to the click detector, and was manually started each time echolocation clicks were heard. Thus all acoustic events, including the transmission of squeep sounds in connection with porpoise interactions were recorded.

Data processing and statistical analyses

Maximum range of relevance

Only surfacings within a range of 400m to the pinger were included in the dataset. The exclusion of surfacings outside this range was based on the following considerations.

Range of precise tracking

The accuracy of tracking decreases the further away from the tracking station the porpoises surface. This is partly because the porpoises are harder to detect at larger distances, which increase the likelihood of missing surfacings, and partly because the relative error of the angles obtained by the theodolite increases with distance.

The accuracy of tracking for most of the observers was assessed. This was accomplished by having them positioning four different stationary targets (the buoys of the experimental area) several times in rapid succession, while using the coarse sight on the theodolite, just as it was done during tracking of porpoises. The positions obtained were compared to precise position of the targets, obtained with the theodolite telescope (30 times magnification). The precise positions were obtained without any time pressure.

In general, the trackers tended to get the correct bearing to the target, whereas the distance deviations were correlated to the distance to the target. Based on these comparisons the acceptable range of precise tracking was set to a maximum of 400m.

Signal-to-noise ratio

As mentioned earlier the source level (SL) of the squeep sounds was approximately 154 dB p-p re 1µPa @ 1m. The signal-to-noise ratio (SNR) at a range of 400m 2) was estimated based on the transmission loss (TL) due to spreading and absorption, and the noise level (P_N = Noise power; DI = receiving directivity index) as follows:.

$$SNR = SL - TL_{(spreading + abs.)} - (P_N - DI) \qquad \text{(Au, 1993)}$$

In this way a rough SNR estimate of 33 dB was obtained for the 400m range.

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2) The 400m limit for accuracy of tracking is not equivalent to a 400m range around the pinger, since the tracking station and the acoustic platform were positioned 150m apart. The difference between the two areas was mainly land and an area with very few positions obtained. The calculations are therefore based on a area with a range of 400m to the pinger.

The duration (256ms) of the squeep sounds is not likely to limit the detection by the porpoises, since it is much longer than the expected integration time of the porpoises ear (bottlenose dolphin, *Tursiops truncatus* ~ 264µs (Au, 1990)).

The signal-to-noise ratio thus leaves plenty of room for the inaccuracies of the estimate, and it is safe to conclude that the porpoises will be able to hear the squeep, even if porpoises have a relatively high detection threshold. The acoustic detection range is therefore equal to or larger than the 400m range of precise tracking, and will not influence the maximum range for tracks to be considered in the analyses. 3)

Statistical analysis

Dive parameter analysis

The four parameters tested were: change in distance to pinger (measured as the change in distance to the pinger between two subsequent surfacings); length of dive (distance between two subsequent surfacings); dive duration (the time between two subsequent surfacings) and the apparent swimming speed (dive length/dive duration, assuming a straight line swimming pattern).

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3) The few positions (*Baseline*: 4/39 and *Active*: 1/17) from the area 400m – 550m northwest of the tracking station, i.e. within the 400m acoustic range, but outside the 400m tracking range, were included in the analysis. It was estimated that the possible vertical angle error of these positions would not affect the overall statistical outcome of the dive parameters tested.

Four types of dives in each *Active* track were considered to be essential for the evaluation of the pinger effect (Fig. 4). The S-dives (Dives during which a squeep sound was emitted) were used to test the immediate effect. To see whether there was a persistent effect on the diving behaviour, the dive immediately following an S-dive (1st dive) and the subsequent dive (2nd dive) were tested. These dives were chosen based on a preliminary exploratory analysis of the results, which showed that the dives, following the 2nd dives, did not differ from these. Finally, the dives prior to the emission of a squeep sound (Pre-dives) were tested to see if the porpoises could be considered unaffected prior to the disturbance by the interactive pinger.

The four groups of dives from *Active* tracks, the S-dives, 1st dives, 2nd dives and Pre-dives, were then tested with a Monte Carlo two-sample randomisation test (Manly, 1991) against the baseline dives, for each of the four test parameters (16 tests in total). One million randomisations were run for each test. All Monte Carlo randomisations require the data to be independent. Therefore all samples to be tested were based on one or in certain cases up to three dives from each track (when multiple trigs occurred in the same track). For the *Baseline* tracks and the pre-dives of the *Active* tracks, the 3rd dive (counted from the beginning of each track) was used in the test. Whenever data from two or three dives was extracted from the same tracks, the dives were never subsequent to each other.

Displacement analysis

The study area was divided into four concentric rings, each with a width of 100m, surrounding the pinger up to a distance of 400m (Fig. 5). For each track it was then determined whether the porpoise had surfaced in the interval (One-Zero sampling).

The occurrence of the porpoises in each interval during *Baseline* tracks was tested against the occurence of porpoises in both *Active* tracks and *no pinger* tracks with Fisher's exact test (Sokal and Rohlf, 1998). A pair wise comparison was chosen over an overall comparison to keep the data independent.

The median of the minimum approach distance for the *Active* tracks and the *Baseline* tracks, respectively, were calculated on the basis of the closest approach for each track. The minimum approach distances of the *Active* tracks were compared to the minimum approach distances of the *Baseline* tracks with a two sample T-test on the transformed data (natural logarithm).

The statistical analysis was carried out using Rundom Projects 2 LITE, Rundom Projects 1.1, SigmaStat 2.0 and Microsoft Excel 2000. Both editions of Rundom were produced according to Manly (1991). A significance level of 5% was used throughout.

RESULTS

Data and effort

Of the 35 hours of tracking, 10 hours remained after the exclusion of biased data (tracks with disturbance and all tracks within one hour of the last squeep sound emission). These 10 hours contained 57 tracks, composed of 8 *no pinger* tracks, 32 *Baseline* tracks and 17 *Active* tracks (Table 2).

Frequency of sound emission

As mentioned above, only *Active* treatment was applied in the 3rd test period. A total of 308 squeep sounds were emitted from the interactive pinger during this test period, when false trigs due to passing outboard motor boats and the very limited number of test squeeps are included (observation time: 47 hours).

Standard beacon mode pingers like the AQUA*mark* 100 and the Dukane *Netmark*™ 1000 pinger would in the same time frame have emitted ~9,669 and 42,300 displacement sounds, respectively. This means that the interactive pinger emitted the equivalent of 1-3% of the displacement sounds emitted by the standard beacon mode pingers.

Echolocation behaviour

The harbour porpoises in *Active* tracks were often heard echolocating previous to triggering the emission of a squeep sound from the pinger. Once this occurred, however, the echolocation activity usually ceased completely (See Figs 6 A, B for an example). As a result, only 18% of the 17 *Active* tracks had more than one trig.

Displacement analysis

No significant difference was found for any of the four 100m intervals around the pinger, when comparing the occurrence of surfacings during *Baseline* tracks with the occurrence during *no pinger* tracks (Fig. 7).

In contrast, a significant difference (P=0.03) was found in the interval 0 - 100m from the pinger, between the *Baseline* tracks (1st test period) and the *Active* tracks (3rd test period) (Fig. 8). No significant difference was found for the remaining three intervals (100-200m: p = 1,00; 200-300m: p = 0,12 and 300-400m: p = 0,06).

The median of the minimum approach distance to the pinger was significantly different (p=0,007) between *Baseline* tracks (72m) and *Active* tracks (114m), when calculated on the basis of all porpoises within a 400m range of the pinger. The closest approach by any porpoise during the *Active* tracks was 60m, compared to 19m for the *Baseline* tracks.

In addition, 60% of the total track time during *Baseline* tracks took place within 150m of the pinger versus 24% of the time during *Active* tracks.

Dive specific response

The harbour porpoises swam away from the pinger in the *Active* tracks when a squeep sound was emitted, but a significant difference was only found in the S-dives for the parameters “change in distance to pinger”, “length of dive” and “duration of dive” and in the 1st dive for the parameter “length of dive” (Table 3).

DISCUSSION

Effect of set-up

There were concerns as to whether the acoustic platform would have an effect on the behaviour of the animals. Any object introduced into the path of the porpoises, such as the stationary boat with its anchor and buoy, could alter the approach distance in relation to the undisturbed route, as well as influence the general behaviour of the porpoises. However, no difference could be detected in the occurrence of surfacings for periods with ordinary *Baseline* tracks compared to *no pinger* tracks. It was therefore assumed that the set up in itself did not significantly affect the positioning of the porpoises in the area.

Comparing data from different test periods

Due to a lower porpoise density than expected, the study had to be conducted over three separate test periods at different times of the year. This could have introduced a bias affecting the analysis. In the 1st test period in August and September of 2002 many females associated with calves were observed. This was not the case in the 2nd and 3rd test period in May and June 2003. Females caring for a calf might have different habitat preferences than single harbour porpoises (Smith and Gaskin, 1983), which could affect their distribution.

However, no difference was found in the occurrence of porpoise surfacings around the pinger in *Baseline* tracks from the 1st period compared to *no pinger* tracks from the 2nd test period. The risk of the porpoises exhibiting a different surfacing behaviour during the 3rd test period merely as a result of the season was therefore considered minimal.

Range of relevance

Using the median approach distance as a measure of how far away porpoises are displaced by pingers is not appropriate unless some distance of relevance is specified. The range of data points to be included in analyses should be based on an area no larger than the expected, or better yet known, acoustic detection range of the pinger. It is also important to evaluate the precision of the tracking, since the maximum distance of precise tracking could be less than the acoustic range of the pinger (as was the case in this study) and therefore be the factor limiting the range of relevance. In several studies this does not seem to have been taken into account. Berggren (2002) reported an average minimum approach distance of 752m to a pinger, and their data included positions at least 1,000m from the pinger. In the same way, Culik *et al.* (2001) reported a median approach distance of 530m based on observations 130 - 1,140m from the pinger.

Also it should be remembered when comparing different studies that the maximum range of precise tracking depends on the height of the observation platform as well as the specific observation conditions. This means that different studies, where the porpoises are displaced similar distances, could obtain different median approach distances, due only to the maximum range of precise tracking.

Effect of the interactive pinger

Displacement and approach distance

A significant difference was found in the proportion of porpoises present within 100m of the pinger when comparing the *Active* tracks to the *Baseline* tracks. In addition, the closest approach during

Active tracks was 60m, whereas almost 30% of the porpoises recorded during *Baseline* tracks got within a 50m distance of the pinger, with the closest approach being 19m. The interactive pinger is therefore efficient in displacing the porpoises from its near vicinity.

In addition to the difference in occurrence of surfacings, 60% of the total track time during *Baseline* tracks took place within 150m of the pinger, versus 24% of the time during *Active* tracks. So, although approximately 80% of the porpoises in *Active* tracks got within 150m of the device, they only stayed there for a short period of time compared to the porpoises in *Baseline* tracks. The reduction in time spent in the vicinity of the pinger indicates that the pinger is triggered fairly quickly after the porpoises enter the range of 150m from the pinger, and that the pinger would be triggered when needed and before the porpoises would get too close to risk entanglement.

The median approach distance in this study is based on surfacings within a 400m radius of the pinger, which according to the estimate of signal-to-noise ratio should be within the acoustic detection range of the pinger, as well as within the maximum range of precise tracking. Although the median approach distance was significantly greater for *Active* tracks, the porpoises were not excluded from an excessively large area (median approach distance: 114m). In fact, the minimum distance recorded, 60m, is comparable to the median approach distance for the *Baseline* tracks (72m). Hence, the interactive pinger seems to have a smaller exclusion zone than the one reported for a standard beacon mode pinger (Culik et al.; 2001: PICE pinger, 130m).

At a distance of 60m (closest approach) the porpoises should not be able to trigger the interactive pinger, if the SL of their echolocation clicks does not exceed the maximum of 172 dB re 1 μPa @ 1m recorded for a porpoise in captivity (Au *et al.*, 1999). However, it has been observed that bottlenose dolphins kept in tanks tend to emit signals with a SL of 170-180 dB, whereas the SL of signals emitted in open water can be 210-225 dB (Au, 1993). It is therefore likely that porpoises are capable of emitting signals higher than 172 dB, and might do so in the wild. With a SL just 1 dB higher than the maximum recorded for a captive porpoise, the animals should be able to trigger the device at a distance of 60m. At the median approach distance of 114m from the pinger the source level of the porpoise clicks would have to be approximately 178 dB re 1 μPa @ 1m in order to trigger the device.

Direct effect of squeep sounds

As seen from the dive parameters, the interactive pinger was efficient in displacing the porpoises during *Active* tracks. The only significant responses, however, were seen in the S-dives, and for a single dive parameter also in the 1st dive. With a mean displacement of 30m, the squeep sounds seems to make the porpoises move away from the pinger as intended, but with a quick return to pre-treatment behaviour.

The fact that no echolocation clicks were detected after the squeep sound emissions, indicates that the hypothesis of pingers alerting porpoises and making them interrogate their surroundings (Dawson, 1994; Kraus, 1999) may not be true. A similar reduction in echolocation signals was recorded by Cox *et al.* (2001) in the vicinity of an active beacon mode pinger. Whether the porpoises in our study stopped echolocating, or merely turned their sonar beam away from the pinger, could not be determined from this set-up.

Noise pollution

Since the source level of the squeep sounds (154 dB p-p re 1µPa @ 1m) is less than the maximum source level recorded for echolocation clicks of a captive harbour porpoise (172 dB re 1µPa @ 1m) (Au *et al.*, 1999), it could be argued that the disturbance caused by these sounds must be minimal. However, the squeep sounds have a much longer duration (256ms) than harbour porpoise clicks (mean duration: ~0,1ms (Møhl and Andersen, 1973; Verboom and Kastelein, 1995; Teilmann *et al.*, 2002) and therefore contain more energy, even compared to click trains with a high repetition rate. In addition, sounds with differing frequency patterns, can elicit very different responses in harbour porpoises (Kastelein *et al.*, 1995). This is probably also true for other species, and the squeep sounds might therefore affect animals that are unaffected by porpoise clicks. Finally, decreasing the number of exposure to these sounds should reduce the possible risk of habituation. For these reasons alone the number of squeep sounds emitted by pingers should be reduced to a level just high enough to displace the porpoises from the near vicinity of a net, without disturbing the marine environment more than necessary.

Since the porpoises in most instances stopped echolocating, or alternatively turned away from the pinger, for a while after a squeep sound had been emitted, the interactive pinger was usually only triggered once in each track. The emission of invasive sound signals is therefore significantly reduced with this type of pinger (1-3%) compared to the traditional Dukane *Netmark*™ 1000, where displacement sounds are emitted continuously with 4 second intervals (Carlström *et al.*, 2002) and the AQUA*mark* 100 pinger, where the sounds are emitted with varying intervals of 5-30 sec (Larsen, 1997). The number of squeep sounds from the interactive pinger included in this calculation includes false trigs due to passing outboard motor boats and squeep sounds emitted in order to test the system. The fully developed interactive pinger will therefore emit even less noise into the marine environment.

CONCLUSION

The interactive pinger was effective in displacing the porpoises from the near vicinity of the device without excluding them from an unnecessary large area. The effect on the porpoise behaviour seemed to be short term and was restricted to the dive where a displacement sound was emitted and the subsequent dive.

The emission of a squeep sound by the pinger had a direct effect on the behaviour of the porpoises, as seen by the immediate cessation of biosonar activity and the avoidance response. Hence the pinger cannot be alerting the porpoises. More likely the squeep sounds were perceived as signalling something unexpected and possibly unpleasant and were therefore avoided.

The possible habituation to the squeep sounds could not be assessed in this study. It was, however, demonstrated that the interactive pinger emitted significantly fewer signals into the habitat (1-3%) than the standard beacon mode pingers. This reduced exposure to the displacement sounds and the unpredictability of the emission most likely would reduce and/or delay habituation.

The prototype of the interactive pinger therefore fulfils the goal of being more porpoise and environment friendly, and from these preliminary studies it also seems to be efficient in displacing the porpoises from the vicinity of the pinger. However, in order to ensure the attention of the harbour porpoises and make them trigger the pinger, even when they are engaged in e.g. foraging behaviour or if they for some reason are not echolocating, an alerting unit needs to be included. The EPIC study (Lockyer *et al.*, 2001) found that artificial click trains simulating a porpoise feeding buzz were efficient in increasing the echolocation activity of captive porpoises. Similar sounds emitted pseudo-randomly over the entire deployment period, but irrespective of porpoise triggering, might therefore prove to increase the efficiency of the interactive pinger.

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FIGURE LEGENDS

Fig. 1:

Map of Denmark and blow-up of the circular experimental area: PB, Pinger buoy; **T**, tracking station; **BN**, north buoy of experimental area; **BW**, west buoy of experimental area and **BS**, south buoy of experimental area. The radius of the experimental area was 150m.

Fig. 2:

Sketch of the acoustic platform.

Hydrophone: 13mm spherical hydrophone (HS/150), **AS**: AQUA*mark* 100 modified for squeep sound transmission. Drawing not to scale.

Fig. 3:

Drawing of the pinger set-up.

AS: AQUA*mark* 100 modified for squeep sound transmission, **Hydrophone**: Trigger hydrophone, **ECD**: Envelope click detector (36dB amplification), **PC**: computer; **MD**: Mini-disc recorder and ▷: preamplifiers, **1** = 20dB, **2** = 26dB.

Fig. 4:

Illustration of the 4 dive types. Each dot in the porpoise series/track represents a surfacing and the lines between them the dives (assuming a straight line swimming pattern). The open star and the closed star represent the start and end of the track, respectively. The light coloured triangles in the porpoise track represent the surfacing before and after a squeep sound emission. The tracking station was positioned in (0,0), and the units of the y- and x-axes are range in m.

Fig. 5:

Map of Fyns Hoved with the four circular intervals for the distribution analysis

The pinger is positioned at the cross, and the width of each concentric ring is 100m. Scale bar = 400m.

Fig. 6: Echolocation behaviour at the time of trig.

A) Waveform of a sound from the minidisk recordings. A is an expansion of the selection marked in white in B. Porpoise clicks appear as spikes and the bracket mark the squeep sound. Scale bar = 0.2sec.

B) After the emission of a squeep sound (i.e. after selection in white) no sonar clicks were detected. The "silence" continued beyond the timeframe of this figure. Scale bar = 2.0sec.

Fig. 7:

Distribution of porpoises during *Baseline* tracks from the 1st test period and *no pinger* tracks from the 2nd test period. *Baseline* (n=28) and *no pinger* (n=8).

Fig. 8:

Distribution of porpoises during *Active* tracks from the 3rd test period versus *Baseline* tracks from the 1st test period. *Baseline* (n=28) and *Active* (n=16). An asterisk marks an interval with a significant difference.

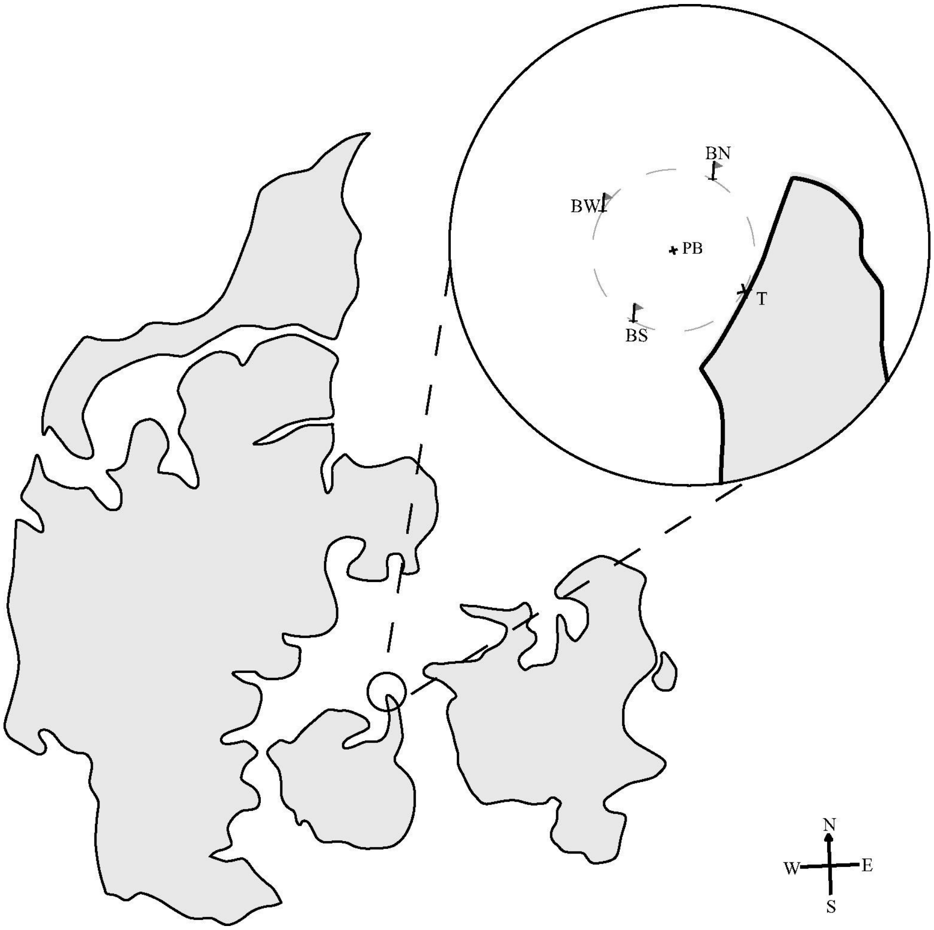
TABLE TITLES ETC.

Table 1: Test periods and strategies applied.

Table 2: Effort and data

Table 3: Mean value and 95% confidence intervals of the dive parameters of the *Active* tracks.

An asterisk marks a significant difference compared to the *Baseline* tracks. The sample sizes are not equivalent to the number of tracks obtained for treatment and control, due to missing surfacings in some of the tracks and/or due to the fact that some of the *Active* tracks had more than one trig.



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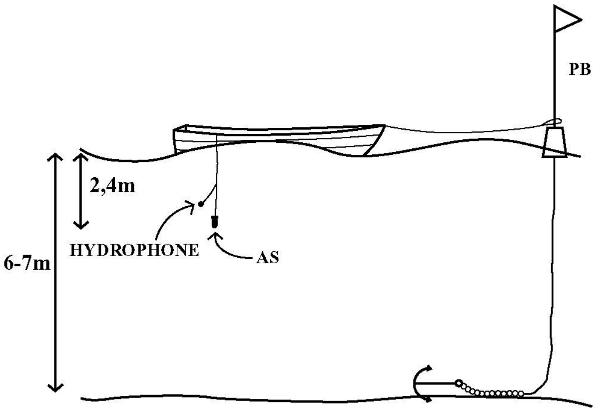

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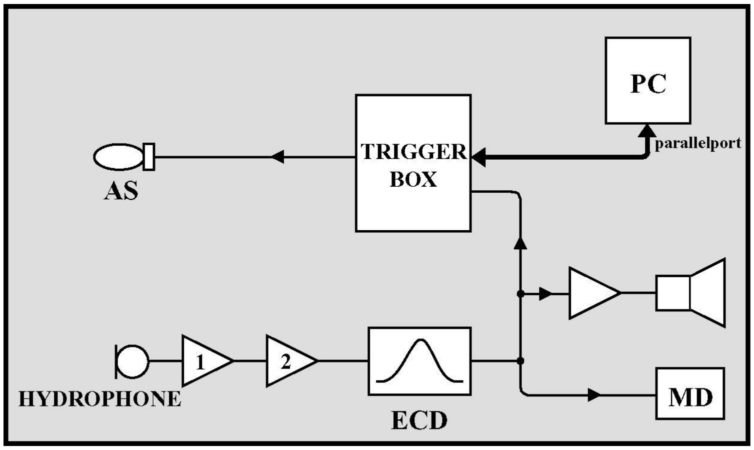

PC
TRIGGER BOX
parallelport
AS
1
2
HYDROPHONE
ECD
MD

Fig. 3:

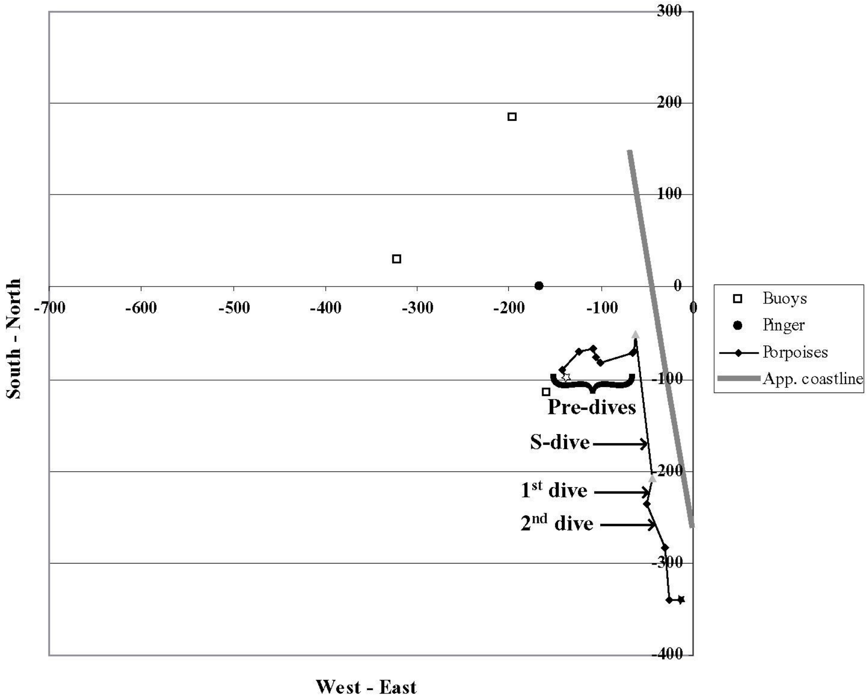
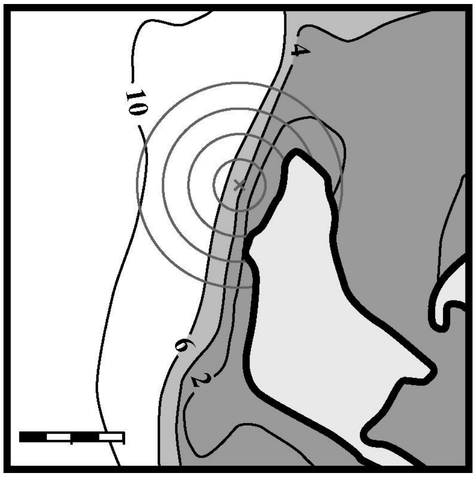

300
200
100
0
-100
-200
-300
-400
-700
-600
-500
-400
-300
-200
-100
0
South - North
West - East
Buoys
Pinger
Porpoises
App. coastline
Pre-dives
S-dive
1st dive
2nd dive

Fig. 4:



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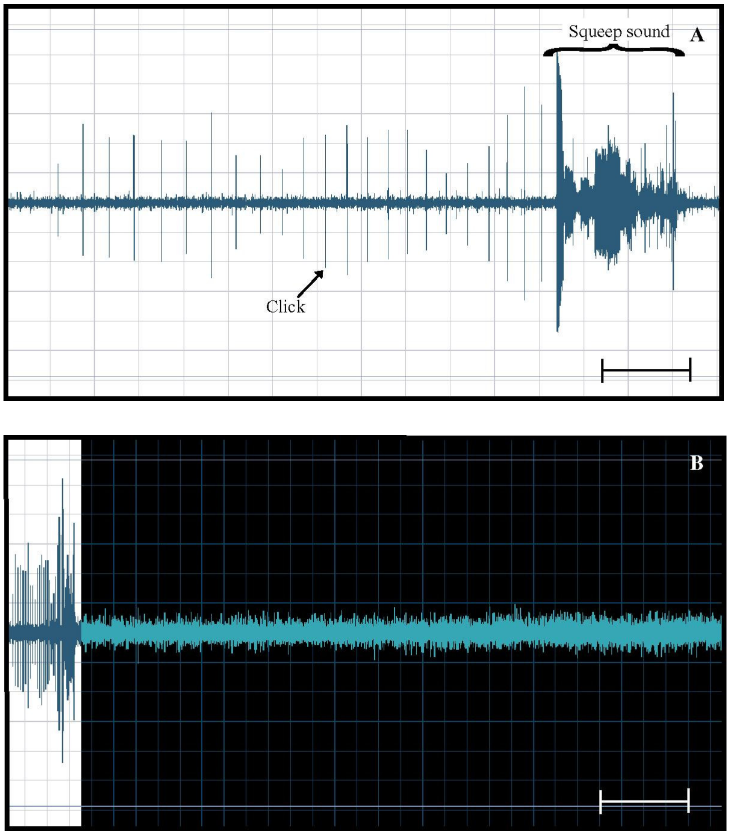
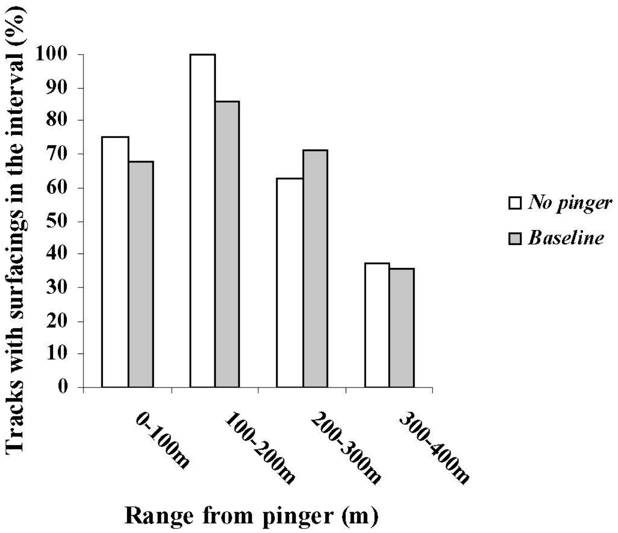
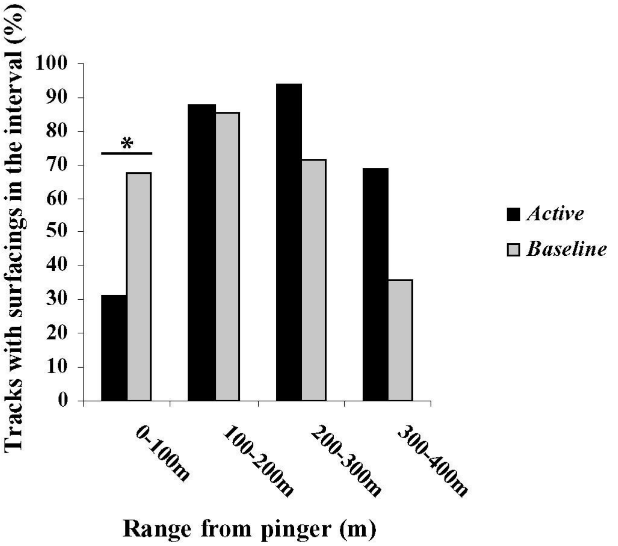


Figs 6 A, B:



Tracks with surfacings in the interval (%)
100
90
80
70
60
50
40
30
20
10
0
0-100m
100-200m
200-300m
300-400m
Range from pinger (m)
☐ No pinger
▨ Baseline

Fig. 7:



Tracks with surfacings in the interval (%)
100
90
80
70
60
50
40
30
20
10
0
*
0-100m
100-200m
200-300m
300-400m
Range from pinger (m)
■ Active
▨ Baseline

Fig. 8:

Table 1:

Test Period	**Date**	**Treatment strategy**
1st	August 10th – September 7th 2002	1st strategy
2nd	May 5th – May 22nd 2003	1st strategy
3rd	June 23th – July 1st 2003	2nd strategy

Table 2:

Observations	**August 2002**	**May 2003**	**June 2003**	**Sum**
Experimental period	27 days	18 days	9 days	**54 days**
Observation days	17 days	9 days	6 days	**32 days**
Observation time (h)	119	71	47	**237**
Total track time (h)	20	9	6	**35**
Track time used for calculations (h)	7	1	2	**10**
Tracks	**August 2002**	**May 2003**	**June 2003**	**Sum**
no pinger	0	8	0	**8 tracks**
Baseline	28	0	4	**32 tracks**
Active	1	4	12	**17 tracks**
Total	29	12	16	**57 tracks**

Table 3:

***Active* tracks**	**S-dive n=17**	**1st dive, n=17**	**2nd dive, n=19**	**Pre-dives, n=4**	***Baseline*, n=39**
Change in distance to pinger (m)	* 30 +/- 22	17 +/- 16	7 +/- 12	3 +/- 3	4 +/- 6
Length of dive (m)	* 69 +/- 29	* 41 +/- 14	24 +/- 8	8 +/- 8	20 +/- 8
Duration of dive (s)	* 44 +/- 14	21 +/- 8	16 +/- 5	7 +/- 6	22 +/- 11
Swimming speed (m/s)	1.4 +/- 0.5	2.4 +/- 0.8	1.6 +/- 0.3	1.0 +/- 0.8	1.5 +/- 0.6

Appendix 1

EQUIPMENT	PRODUCT AND COMPANY
Digital theodolite	Geodimeter/Trimble Total station 468 Trimtec AB, Finlandsgatan 58, 16474 Stockholm, Sweden
AQUA*mark* 100	Aquatec Subsea Ltd, Hartley Wintney, RG27 8NY, UK
Hydrophone	HS/150 Sonar Research and Development, Ltd, East Yorkshire, UK
Pre-amplifiers	ETEC, A1001B Electronic Technical Engineering and Construction, Copenhagen, DK
Envelope click detector	ECD-1 NewLeap Ltd, Cardiff, Wales, UK
Trigger box	Aquatec Subsea Ltd, Hartley Wintney, RG27 8NY, UK
Laptop	Crest, GO_5 Fujitsu Siemens Computers, Germany
Software	AQ441 Aquatec Subsea Ltd., Hartley Wintney, RG27 8NY, UK
Speaker	Archer, mini amplifier-speaker Radio Shack Corp. Ft. Worth, TX 76102, USA
Mini-disc recorder	MZ-R55 Sony Corporation, New York, USA

Abbreviations and glossary

***Active* tracks:** A squeep sound is emitted every time the interactive pinger has been trigged by a porpoise sonar

AS: AQUA*mark* 100 unit modified to emit squeep sounds

***Baseline* tracks:** The pinger present, but not activated.

BN: North buoy of the observation area

BS: South buoy of the observation area

BW: West buoy of the observation area

DI: Receiving directivity index (dB re 1μPa)

GPS: Global Positioning System

PB: Pinger buoy, centre in the experimental area

Pre-dives: All dives prior to the emission of a squeep sound in an *Active* track

P_N: Noise power (dB re 1μPa rms)

S-dives: The dive, in an *Active* track, where the squeep sound was emitted

SL: Source level (dB re 1μPa @ 1m)

SNR: Signal-to-noise ratio (dB)

Squeep: A specific square wave or frequency sweep meant to displace the porpoises

TL: Transmission loss (dB re 1μPa)

1st dive: The first dive after the dive with a squeep sound emission

2nd dive: The second dive after the emission of a squeep sound