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Författare
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Sammanfattning

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Nyckelord

Keyword AQ626 Interactive pinger, AQUA*mark* 100™, by-catch, displacement, harbour porpoise, *Phocoena phocoena*

Final thesis

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Joanna Stenback

LiTH-IFM-Ex—06/1638—SE

Contents

1. Abstract

Serious concern has been raised for the sustainability of *Phocoena phocoena* populations, since they are threatened by extensive by-catch in commercial fishing gear. Beacon-mode pingers have significantly reduced by-catch in fishery trials, which have led to mandatory use in several countries. However, beacon-mode pingers emit displacement sounds continuously. The continuous sound source may cause excessive noise pollution, habituation in the long term and exclusion from important habitats. This study assessed the behavioural reaction of wild *P. phocoena* to the alternative AQ626 Interactive Pinger, which always emits naturalistic alerting sounds to stimulate echolocation, but only emits displacement sounds in active state when triggered by sonar. The interactive pinger was compared to the beacon-mode AQUA*mark* 100™ pinger in a simulated fishery situation. The results showed a clear, short-term, displacement effect in the dive after the first trig, with a quick return to pre-trig behaviour and without exclusion from the area. Unfortunately, the displacement sounds from either pinger did not stop the animals from passing through the array of pingers. Conclusively, the most important effect of displacement sounds from either pinger might not be to displace animals, but to increase their awareness of the presence and location of nets. Since the AQUA*mark* 100™ pinger is known to reduce by-catch, in addition to transmitting much less sound, the interactive pinger should be considered a possible, and more environmental friendly, mitigation alternative to the beacon-mode pinger.

Keywords: AQ626 Interactive pinger, AQUA*mark* 100™, by-catch, displacement, harbour porpoise, *Phocoena phocoena*

2. Introduction

Phocoena phocoena L, the harbour porpoise, is a small whale belonging to the order Cetacea. *Phocoena phocoena* is distributed throughout coastal temperate regions of the northern hemisphere (Donovan & Bjørge 1995, Read & Westgate 1997). It is abundant in the North Sea, the most common cetacean in Danish waters but unfortunately the only one in the Baltic Sea (Berggren 1994). An extensive survey (SCANS) in the North Sea and adjacent waters in 1994 estimated in total about 340,000 individuals of *P. phocoena* (Hammond et al. 2002). Despite these numbers, high levels of mortality caused by by-catch in commercial fishing gear, mostly bottom-set gillnets, greatly threaten *P. phocoena* populations (Lowry & Teilmann

1994, Kraus 1997, Tregenza et al. 1997, Vinther 1999, Read 2000, Berggren et al. 2002) and concerns of their sustainability in the North Atlantic have been raised (Donovan & Björge 1995). According to ICES (2003), the population in the Baltic Sea and adjacent waters has declined dramatically, leading to special concern (Berggren 1994, Kinze 1994, Berggren & Arrhenius 1995, Koschinski 2002). Other anthropogenic factors such as pollution, habitat degradation and disturbances also seem to have serious negative impact on *P. phocoena* populations (Aguilar & Borrell 1995, Koschinski 2002).

The concerns led to implementation of ASCOBANS, the "Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas" (ASCOBANS 1997). This conservation and management plan stated that *P. phocoena* populations should be restored and/or maintained at a level of 80% or more of the carrying capacity, and that the yearly by-catch may not exceed 2 % of the population.

Different mitigation methods have been suggested and evaluated to ease the by-catch pressure on *P. phocoena* populations, such as time/area closures (Trippel et al. 1999 & Murray et al. 2000) and net modifications (Mooney et al. 2004). However, another very promising by-catch mitigation method is acoustic alarms, or "pingers", which emit high frequency, pulsed, sounds (Trippel et al. 1999). Pingers have significantly reduced by-catch of *P. phocoena* in commercial fishery trials (Kraus et al. 1997, Larsen 1997 & Trippel et al. 1999). These results led to mandatory use of pingers in the Danish wreck-gillnet fishery (Larsen et al. 2002b) and from June 2005 in many fisheries the European Union, e.g. the North and Baltic seas (Anonymous 2004).

The mechanisms behind the by-catch reducing effect of pingers have previously been poorly understood (Kraus 1999). Experiments on the reactions of *P. phocoena* to pingers in captivity (Kastelein et al. 2000, 2001 & Lockyer et al. 2001) and in the field (Cox et al. 2001 & Culik et al. 2001) do however indicate that *P. phocoena* avoid the sounds. During the development of an effective pinger, many types of sounds of various frequencies, source levels and pulse intervals etc. have been tested (Kastelein et al. 2000, 2001 & Lockyer 2001). The reason why *P. phocoena* get entangled in the first place seems to be the difficulty for cetaceans to detect gillnets (Dawson 1991). Gillnets are generally made of nylon monofilament, which have a poor sonar echo, and might not always be detected (Pence 1986, cited by Dawson 1991). However, according to Goodson et al. (1994) it is possible that cetaceans can detect nets but do not perceive them as a threat.

The pingers used so far are all of “beacon-mode” type, i.e. they emit displacement sounds frequently and continuously while deployed, irrespective of the presence of animals in the area. This may result in excessive noise pollution in the underwater environment and, with widespread pinger deployment, lead to exclusion of *P. phocoena* from large portions of its natural habitat, forcing them into sub-optimal areas (Culik et al. 2001). To reduce this impact an “interactive” pinger was developed, the AQ626 Interactive pinger (Aquatec Electronics Ltd., UK). The interactive pinger only emits displacement sounds when it has been activated, triggered, by sonar. In addition to reducing noise emissions to the environment, the risk of habituation to the sounds will probably be lower when subjected infrequently (Lockyer et al. 2001). It is crucial that *P. phocoena* will hit the pinger unit with its sonar beam. When foraging they engage in the "bottom grubbing", where the animal is positioned with the snout close to the bottom and the sonar beam, with which it echolocates, is aimed downwards (Lockyer et al. 2001). Since the sonar is not directed at the net in this position it becomes very difficult for animals to discover bottom-set nets in time (Lockyer et al. 2001), especially since the sonar reflection of a gillnet is very poor (Pence 1986, cited by Dawson 1991). To stimulate echolocation towards the net also during bottom grubbing, interactive pingers emit alerting sounds, which are simulated sonar clicks-trains. This increases the chance of making animals aware of the presence of net and pingers.

A single prototype of the interactive pinger was tested on wild *P. phocoena* in the NAPER (New Alternatives to Porpoise Entanglement Reduction) project, where animals were only displaced from the near vicinity of the pinger and not excluded from a larger area (Poulsen 2004). Sound emissions were also reduced to 1-3% of the emissions from standard, beacon-mode pingers (Poulsen 2004).

The NIPPER (Nordic Interactive Pinger for Porpoise Entanglement Reduction) project, which this thesis is part of, takes a natural step further to evaluate the by-catch reducing effect of the interactive pinger. We tested an array of pingers in a simulated net, i.e. several pingers deployed in a row, approximating a real fishery situation in which pingers would be attached to the nets in certain intervals.

This thesis aimed to assess the immediate displacement effect of the interactive pinger on *P. phocoena* in the wild. Previous trials with a single prototype resulted in a direct and noticeable but short term avoidance reaction to emitted displacement sounds (Poulsen 2004). Therefore the first hypothesis of this study was that *P. phocoena* would show an avoidance reaction to the array of interactive pingers after trig. The second hypothesis was that *P. phocoena* would not trigger a subsequent pinger after triggering a first one, based on results from the NAPER study where no echolocation sounds were recorded after a trig (Poulsen 2004). A very interesting and important question for this project was how the array of pingers would be perceived since it always emitted alerting sounds. The third hypothesis was that *P. phocoena* would not pass in between pingers since the spatial scale information provided by the emitted sounds hopefully would be enough for *P. phocoena* to avoid the array. Another question we sought answers to was if the interactive pinger would generate an exclusion zone on P. phocoena around the array or if they would use the entire experimental area, as well as how close their approaches to the array would be.

The crucial characteristics of this new by-catch mitigation method would thereby be tested - a more friendly alternative for both the environment and *P. phocoena*.

3. Material and Methods

3.1 Study site and field period

The study was conducted from May 23 to June 19 and August 15 to September 8 2005, in the waters northwest off Fyns Hoved (Figure 1). Fyns Hoved is situated at the Island of Funen, Denmark, and constitutes the northern part of the Hindsholm peninsula.

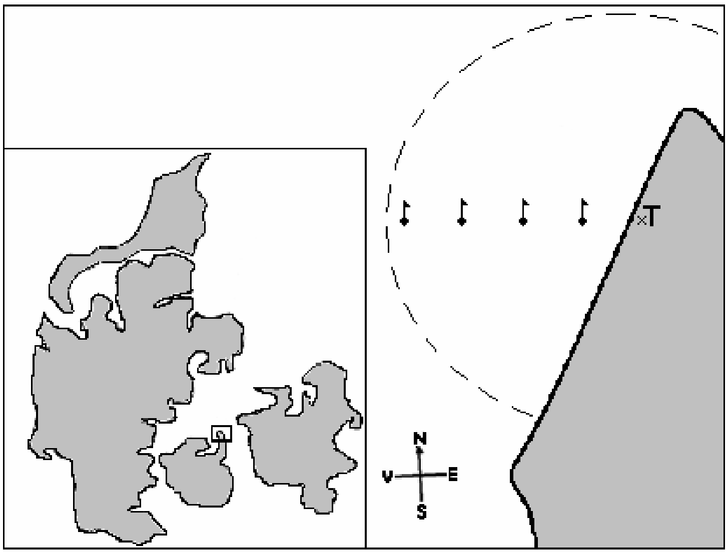

Figure 1. Map of Denmark with the experimental site on Fyns Hoved in magnification. T=tracking station, the flags are the pinger buoys and the radius of the circle marking the site is 400 m with the tracking station as centre point. (Figure modified after Poulsen 2004)

3.2 Experimental design

An array of four pingers was deployed in an area with a high density of *P. phocoena* (Heidejorgensen et al. 1992). The array was positioned at an approximate straight angle from the coast. Pingers were deployed 100 m apart with the closest pinger 75 m from shore. Parallel to, and 2-10 m south of the pinger array, a simulated bottom-set gillnet was positioned. To each pinger unit a HS/150 13mm spherical hydrophone (Sonar Research and Development Ltd, UK) was attached, and separate underwater cables resting on the sea bed connected them to the acoustic listening post on the beach. This improved the detection rate of *P. phocoena* and enabled recording of echolocation sounds. Each pinger unit included a porpoise click logger (PCL), additionally recording the acoustic activity. Observations and tracking of pods (groups or individual animals) of *P. phocoena* entering the experimental area was conducted to receive information on their movement patterns and hence their reactions during treatments. The tracking station was positioned at the top of a 20 m high hill with the array and observational area just below. Movements of *P. phocoena* were recorded with a digital theodolite (Geodimeter 468) connected to a laptop running Cyclopes (The University of Newcastle, Callaghan, NSW 2308, Australia), a custom made tracking software. The pingers used in the study were the AQ626 Interactive Pinger and the commercial pinger AQUA*mark* 100™ (Aquatec Electronics Ltd., UK). The conventional pinger used in fisheries was incorporated to directly compare the behaviour around an array of the interactive pinger with an array of conventional pingers. The pingers were deployed from a small boat in the morning, just before the start of an observation day, and hauled again in the evening.

3.2.1 Experimental treatments

- *Alerting*: The interactive pinger transmits alerting sounds with random intervals of 30-60 s, irrespective of triggering, with PCL and sound monitoring functions activated.
- *Active*: When triggered the interactive pinger emits displacement sounds in a set of four emissions, with random 5-30 s intervals. Alerting sounds are transmitted with random intervals of 30-60 s, irrespective of triggering, with PCL and sound monitoring functions activated.
- *Aquamark*: The commercial pinger AQUA*mark* 100™ continuously emits deterrent sounds with random intervals of 5-30 s.

Each treatment was deployed for one full day at a time, decided by random selection. Treatments were not changed during the day since that might cause immeasurable and unnecessary disturbance to animals.

3.2.2 Simulated gillnet and pinger deployment

The simulated gillnet consisted of a float line made of a rope (ø 11 mm) with floats (110 x 55 mm) attached 2 m apart along the entire line. The float line was positioned on a height of 1.6 m above the sea bed by thin lines attached to anchors each 100 m. Surface buoys marked the middle anchors and flag buoys marked the ends of the float line. The float line remained in the water during both field periods.

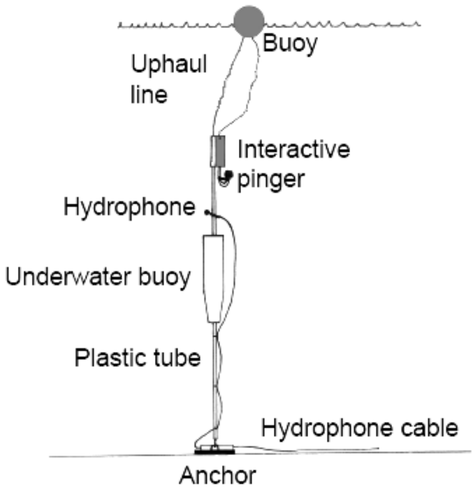

Figure 2. The sketch demonstrates the pinger deployment setup, which keeps each pinger steady in the array and at the same level above the bottom (2.2 m).

The pinger deployment setup kept the pingers 2.2 m above the sea bed (Figure 2). A plastic tube (ø 20mm) was attached to an anchor plate at the sea bottom. The plastic tube was inserted through a white underwater buoy (ø 200 mm x 500 mm) and ended about 0.5 m above the top of the buoy. A rope ran through the tube and was attached to a small buoy at the surface. To the pinger a thin retrieval rope and a narrow plastic funnel were attached. The funnel fitted smoothly on the upper end of the plastic tube and let the pinger stay put at the correct place. At deployment, the rope running from the anchor to the surface buoy was inserted through the funnel, and reattached to the buoy. The pinger was lowered until it set on the top of the plastic tube, the surface buoy was freed and the anchor line remained slack. The small buoy would ease the pulling on the pinger from wave action and hopefully reduce any wave related noise that may result in false trigs. Both types of pingers were deployed in the same manner.

The interactive pingers' waterproof unit was cylindrical (255 mm x ø 67 mm) and contained all electronics, except for an external ball transducer. A salt water sensitive switch turned the unit on when submerged into water and off when hauled. The unit functioned as sound detector and transmitter, and additionally as a data logger of settings, type of sound emitted, intensity of sonar clicks recorded along with a precise timestamp (µs).

The interactive pinger's receiving system detected incoming sonar clicks. Three consecutive clicks within a second, with amplitudes of a certain level, were needed to trigger the pinger. The interactive pinger unit was set to emit a sequence of four displacement sounds when triggered. The sequence was chosen from a repertoire of eight different sounds (Appendix 1), changing to the next in line after each transmission. These sounds were all broad-band and multi-harmonic, lasting approximately 300 ms, with a peak-to-peak source level of 149 dB p-p re 1 µPa at 1m. The Aqua*mark* 100™ units emitted standard Aqua*mark* 100 ™ displacement sounds, the same as for the interactive pinger (Appendix 1), but they were 286 ms long and had a source level of 154 dB p-p re 1 µPa at 1m.

The alerting sounds were intended to be simulated *P. phocoena* sonar click trains, randomly emitted from a repertoire of eight different click repetition rate patterns, all with differently increasing repetition rate and duration (Appendix 1). The source level of the alerting sounds (126-138 dB p-p re 1 µPa at 1m) was intentionally lower than real clicks from *P. phocoena* (up to at least 190 dB p-p re 1 µPa at 1m) so that an area larger than the direct vicinity of the array would not be affected by the sounds.

The sounds used are the result of many years of experiments and trial and error processes with different sound types (Kastelein et al. 2000, 2001 & Lockyer et al. 2001)

3.2.3 Acoustic monitoring

Underwater acoustic monitoring of echolocation activity of *P. phocoena* complemented the logging function of the interactive pinger unit and the visual observations. The system included a hydrophone to each pinger, attached on the plastic tube just below the pinger unit fixation spot (Figure 2). The hydrophones were connected to waterproof containers with a preamplifier, which allowed sending of signals through the underwater cables on the sea bed to the acoustical recording station on the shore. Each cable was connected to a PCL and a speaker. When sonar clicks were heard, recordings started and the time was noted. A clock linked to an atomic clock was used on each workstation to synchronise acoustic and tracking data.

3.2.4 Observations and tracking

The observation station was comprised of the theodolite, a laptop and assistant positions, each operated by an observer. The theodolite observer searched for and tracked animals. With the theodolite each surfacing position of a followed animal, including horizontal and vertical angles along with a time stamp, was recorded. Before each session the theodolite was calibrated for horizontal angles against a reference rock with a known compass bearing. Additionally, positions of boats passing through the area (disturbance factor), the pinger buoys and the tide pole were taken when not tracking. Tidal changes could be up to 0.5 m and were recorded at regular intervals. A position was taken on the water surface on a tide pole, steadily raised in the water a few meters out. The movements of pods tracked with the theodolite were followed on the laptop screen, since the program connected subsequent positions to make *tracks*. A pod was tracked from when it appeared in the area until it was out of sight or another pod came closer to the array, then we shifted focal pod. All relevant information on each track, such as pod size, number of calves, which animal in the pod was tracked and disturbances in the area was noted. When more than one pod of animals were spotted in the area, the theodolite observer would generally track the one closest to the pinger array and follow it until it was out of sight. If another pod was spotted closer to the array, then that pod would be followed. When a pod consisted of more than one animal the theodolite observer focused on following the same focal animal. If another animal in the pod came much closer to the array than the focal animal, that animal would become the focal animal. All such changes in focal animal or changes between pods were recorded. The assistant helped keeping track of animals in the area as well as assisting in reporting weather and boat traffic positions regularly.

Observations were conducted for full days (as many hours as possible) during daylight when sea state was two or less and if it was not raining heavily or the sightability was poor. Observers rotated between the three positions (assistant, laptop and theodolite) every 30 minutes and had 30 minutes pause after operating the theodolite.

3.3 Data processing

Only positions of pods within a range of 400 m from the observation post were further processed, based on the precision of tracking (Poulsen 2004).

The observation height varied with tidal changes. To correctly be able to calculate distances and coordinates to surfacing positions, it was necessary to correct the observation height for tidal changes. This was conducted by measuring the exact distance from the theodolite in eye height, with a built-in laser, to a reflector held at the water surface by the tide pole. Tidal measurements were then conducted continuously during observation days by taking positions on the water surface by the pole without the reflector. Values obtained each day, by geometrical calculations, gave a trend line from which the observation height at certain times could be retrieved. With all distances and co-ordinates known it was possible to further calculate values of the dive parameters.

The distribution of *P. phocoena* in the experimental area during the different treatments was assessed by dividing the area surrounding each pinger into eight circular intervals. Each interval had a width of 50 m and was increasing in distance to the pinger. For each track it was determined if the animal had entered each area. It was assumed that animals that entered one interval had also entered the intervals further out from the pinger.

3.4 Dive behaviour analyses

3.4.1 Dive parameters and definitions

Four dive parameters were used in the analyses:

- *Dive duration* - the time (s) between two subsequent surfacings
- *Dive length* - the distance (m) between two subsequent surfacings
- *Swimming speed* - the swimming speed between two subsequent surfacings, assuming a straight line swimming pattern (m/s)
- *Swimming direction* - the change in distance to the nearest pinger between two surfacings, divided by the distance between the two surfacings forming the dive. A negative or positive value close to 1 indicates that the animal swam directly towards or away from the pinger, respectively. When close to zero, the animal swam in a circle with the pinger in its centre, without changing the distance to it.

A *track* is connected surfacing positions of one animal in a pod of animals that is followed through the experimental area and recorded with the theodolite. Depending on the treatment applied, tracks are referred to accordingly as either *active*, *alerting* or *aquamark* tracks.

In *active* tracks the pingers in some cases were triggered several times within the four transmissions following a trig. This initiated a new set of four transmissions, and hence several dives were affected by the displacement sounds. The mean number of dives during which displacement sounds were emitted was six. This number was chosen as the dives during which a reaction would be reasonable to detect, and was used for all treatments.

The *pre-dive* was defined as a mean of the 2^{nd}, 4^{th} and 7^{th} dive from the start of a track, i.e. three dives unrelated to each other and the *trig-dive*, and never immediately prior to deterrent sound emission (*trig-dive*). This eliminated the bias that a change in the *Trig-dive* was not a reaction but the normal swimming pattern. Phocoena phocoena often swim by alternating two or three short dives and one long dive.

Definitions used for the statistical analyses can be found in table 1.

Table 1. Definitions of dives and a specific area used in the statistical analyses as well as the respective treatment being applied.

	Treatment	Definition
Alerting dives	Alerting	A mean of six subsequent dives; two dives just before the closest dive to the array, the closest dive and the three subsequent dives.
Aquamark dives	Aquamark	A mean of six subsequent dives; two dives just before the closest dive to the array, the closest dive and the three subsequent dives.
Trig-dive	Active	The dive during which the first displacement sound was emitted
Pre-trig dives	Active	A mean of the six dives just prior to the trig-dive.
Post-trig dives	Active	The five dives subsequent to the trig-dive.
Trig-period dives	Active	The trig-dive plus the five post-trig dives.
Pre-dive	Active	A mean of the 2^{nd}, 4^{th} and 7^{th} dive from the start of a track
Trig-series	Active	A series of dives; the pre-dive and the trig-period dives.
1^{st} trig-series	Active	The 1^{st} time the pinger was triggered. If triggered several times within the seven dives of this trig-series, then those trigs were included in the 1^{st} trig-series

2nd trig-series	Active	The 2nd time a pinger was triggered, after all displacement sounds following a trig in the 1st trig-series had been transmitted.
3rd trig-series	Active	The 3rd time a pinger was triggered, after all displacement sounds following a trig in the 2nd trig-series had been transmitted.
Risk area	Alerting Aquamark Active	A 50 m radius area around either pinger, an arbitrarily defined area of immediate entanglement risk

3.4.2 Statistical analyses

All statistical analyses were conducted in SPSS 11.5 for Windows.

To assess the general behaviour of *P. phocoena* between the three treatments, a comparison of the dive behaviour was conducted in two analyses. First the *alerting* and *aquamark* dives were compared to the *pre-trig dives* and the *trig-period dives* in *active*. Secondly the *trig-dive* was compared to the *alerting*, *aquamark* and *pre-trig dives*. The dive parameters dive length, dive duration and swimming speed were analysed with one-way ANOVA and Tukey's post hoc when applicable.

A more specific analysis of the immediate reaction of *P. phocoena* to displacement sounds was conducted, comparing all dives for the parameter swimming direction in a *trig-series* with each other. Dive duration, dive length and swimming speed were compared in an analysis between dives in the 1st *trig-series*. All analyses of dives in trig-series were conducted with one-way ANOVA and when applicable with a subsequent Tukey's post-hoc test.

To further investigate whether the reaction would change with subsequent exposures, pods with representatives in all three trig-series were compared. Each dive in the 1st *trig-series* was compared with its corresponding dives in the subsequent *trig-series*. This was conducted in non-parametric related samples Friedman tests.

The total duration a pod remained within the *risk area* was compared for *active*, *alerting* and *aquamark* tracks. In addition, the duration from the first trig was transmitted until the pod had left the *risk area* of the triggered pinger, in *active* tracks, was compared with the total time in the *risk area* for the other two treatments. The relation between the duration of the pods inside the *risk area* before and after a trig in the *active* treatment was calculated as a measure of avoidance of the displacement sound. Both analyses were conducted with a non-parametric Kruskal-Wallis test.

The proportion of pods passing through the array was analyzed for the different treatments in Pearson's χ^2-test. In tests where the expected value was below five, the statistical program (SPSS) automatically conducted a Fishers' exact test.

A distribution analysis of *P. phocoena* compared the proportion of surfacings in similar intervals between treatments in a Fisher exact test or χ^2-test.

The frequency of pods with their closest approach distance to a pinger in intervals within the experimental area, as well as the minimum approach distances and medians of minimum approach distance were compared between treatments.

4. Results

4.1 Effort and data

Table 2. The effort and the number of tracks recorded and used from the experimental periods 2005

Date	**Effort**		**# tracks total (# used for analysis)**				**Total tracking time**	
	Days	*h min*	*alerting*	*active*	*AQUAmark*	*total*	*h*	*% obs.time*
May June	*6 of 23*	*41 38*	*5(5)*	*25(8)*		*30(13)*	*2(1)*	*6 (3)*
Aug Sept	*15 of 23*	*140 28*	*85(55)*	*93(47)*	*28(14)*	*106(116)*	*33(25)*	*24 (18)*

None of the observations recorded in May-June was included in the analysis because they were too few data to analyse (Table 2).

4.2 Dive behaviour

4.2.1 General comparison of dive parameters between treatments

No significant differences were found in dive length (ANOVA; $F_{(3,77)}=1.448$; $P=0.235$), dive duration (ANOVA; $F_{(3,77)}=0.387$; $P=0.763$) or swimming speed (ANOVA; $F_{(3,77)}=0.407$; $P=0.748$) between *pre-trig-dives, trig-period-dives, alerting-dives* and *aquamark-dives.*

The duration between the dives was significantly different (ANOVA; $F_{(3,77)}=8.595$; $P=0.000$) and a Tukey's post hoc test showed that the *trig-dive* was significantly longer than the *pre-trig-dives* ($P=0.002$; df=3), *alerting*-dives ($P=0.000$; df=3) and *aquamark*-dives ($P=0.004$; df=3). No significant differences were found in swimming speed (ANOVA; $F_{(3,77)}=0.868$; $P=0.461$) or dive length (ANOVA; $F_{(3,77)}=1.860$; $P=0.143$).

4.2.2 Specific analysis of dive parameters in series of dives after trig

A pattern in swimming direction could be seen for the dives in the 1st *trig-series* (Figure 3a). Prior to, and during the first emission of displacement sounds, the swimming direction was towards the pinger, followed by the 1st *post-trig-dive* directed away from the pinger (Figure 3a; Table 2). The following dives were slowly but increasingly directed towards the pinger again. A pattern of gradual change in swimming direction could also be seen for the dives in the 2nd *trig-series*, however the turning point was in the 2nd *post-trig-dive* (Figure 3b).

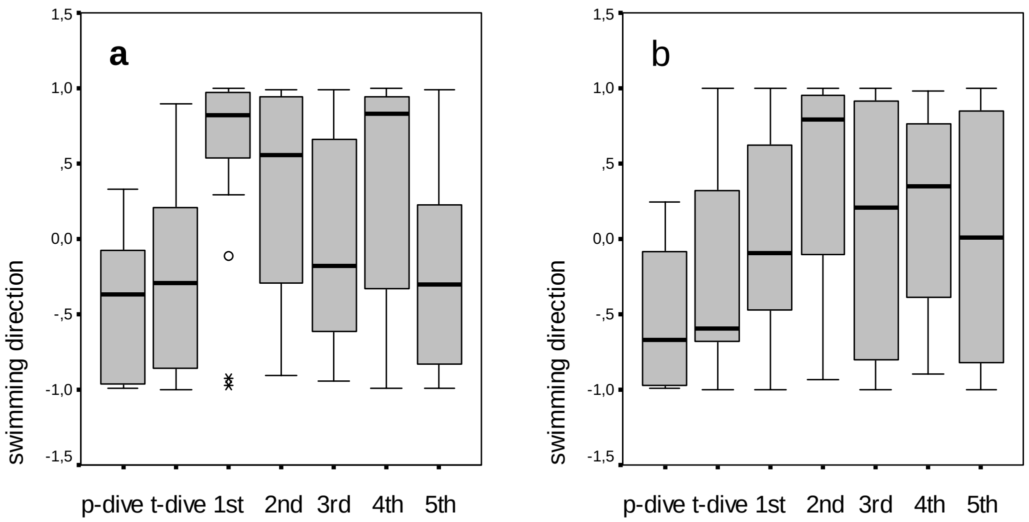

Figure 3. Variations in swimming direction illustrated for the pre-dive (p-dive), trig-dive (t-dive) and the 1st to 5th post-trig dives in the a) 1st trig-series, where there was a significant difference between the trig dive and 1st post-trig dive (Tukey's post hoc; P=0.007; df=6,111), and in the b) 2nd trig-series, where significant differences were found (ANOVA; $F_{(6,77)}$=2.336; P=0.040) between the pre-dive and 2nd post-trig dive (Tukey's post-hoc; P=0.022; df=6). The unit of the y-axis is the orientation in relation to the triggered pinger, swimming towards (negative value) or away from (positive value) the pinger.

Table 2. Bold text indicates significant values in the comparison of swimming direction between pre-dive, trig-dive and the 1st to 5th post-trig dives in the 1st trig-series; (ANOVA; $F_{(6,111)}$=5,184; P=0.000) and Tukey's post-hoc; df=6.

	pre-dive	trig-dive	1st	2nd	3rd	4th	5th
pre-dive	*	0.989	**0.001**	**0.023**	0.563	**0.025**	0.983
trig-dive	*	*	**0.007**	0.107	0.922	0.115	1.000
1st	*	*	*	0.967	0.180	0.962	**0.016**
2nd	*	*	*	*	0.718	1.000	0.174
3rd	*	*	*	*	*	0.736	0.960
4th	*	*	*	*	*	*	0.184
5th	*	*	*	*	*	*	*

There were no significant differences between any of the dives in the 3rd *trig-series* (ANOVA; $F_{(6,49)}=1.921$; $P=0.096$).

When comparing similar dives of all three *trig-series*, there were significant differences for the 1st *post-trig dive* and the 4th *post-trig dive* (Figure 5a and b).

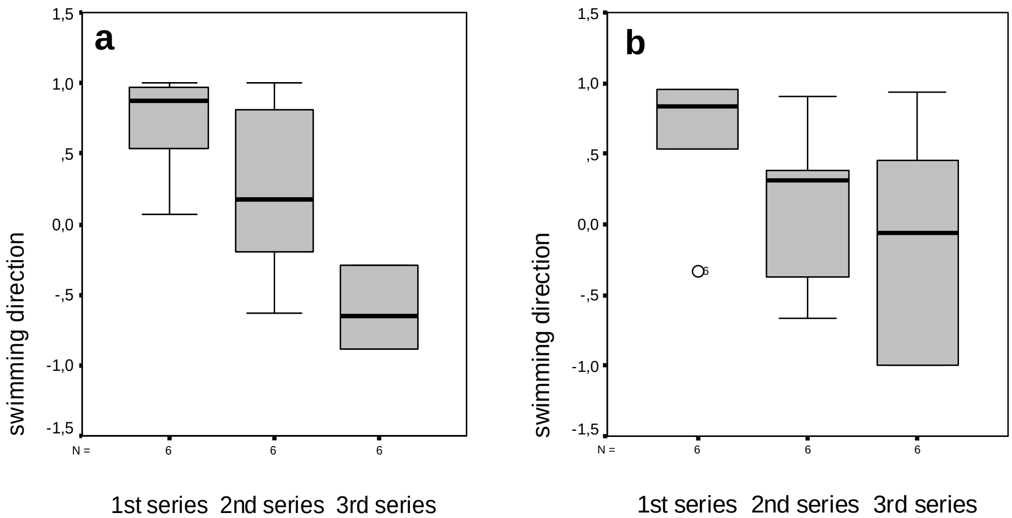

*Figure 5. The swimming direction in the 1st, 2nd and 3rd trig-series for a) the 1st post-trig dive (Friedman test; N=6, $\chi^2_{(2)}=8.333$; P=0.016) and b) the 4th post-trig dive (Friedman test; N=6, $\chi^2_{(2)}=6.333$; P=0.042)**.** The unit of the y-axis is the orientation in relation to the triggered pinger, swimming towards (negative value) or away from (positive value) the pinger.*

The duration of dives within the 1st *trig-series* (Figure 6) were significantly different (ANOVA; $F_{(6,108)}=4.303$; $P=0.001$). The *trig-dive* duration was significantly longer than the *pre-dive,* the 1st, 3rd and 4th *post-trig dive* (P=0.023, P=0.000, P=0.011 and P=0.163 respectively; df=6; Tukey's post hoc).

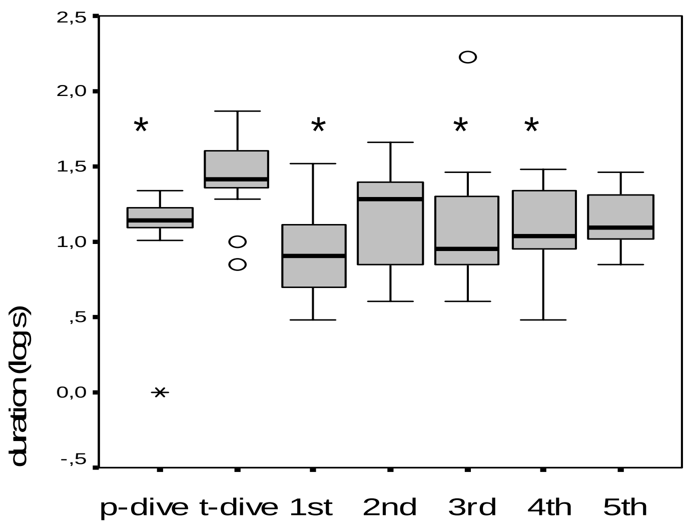

Figure 6. The duration (logarithmically transformed) of dives in the 1st trig-series. Dives significantly different from the trig-dive (t-dive) are marked with an asterisk; the pre-dive (p-dive), the 1st, 3rd and 4th post-trig dives (P=0.023, P=0.000, P=0.011 and P=0.016, respectively; df=6; Tukey's post hoc).

4.3 Interaction with the pinger array

4.3.1 Duration within the risk area

There were no differences in total duration within the risk area for *active*, *alerting* or *aquamark* treatments ($\chi^2_{(2)}$=4.128; P=0.127), nor in the duration after trig within the risk area for *active* vs. the total duration in the risk area for *alerting* and *aquamark* ($\chi^2_{(2)}$=4.128; P=0.127). For both these analyses the Kruskal-Wallis test was used.

In the *active* tracks, approximately 30% of the total time spent in the risk area was before a pinger was triggered, and hence 70% after the pinger was triggered.

4.3.2 Passage through the array

A higher proportion of pods passed through the array during the *aquamark* treatment compared to the *active* treatment (Fishers' exact test, P=0.049). Figure 7 shows the number of all pods coming within the experimental area that were passing through and not passing through the array for each treatment. During the *aquamark* treatment only seven pods (of 14) entered the risk area, compared to 28 (of 47) and 27 (of 55) for *active* and *alerting* respectively.

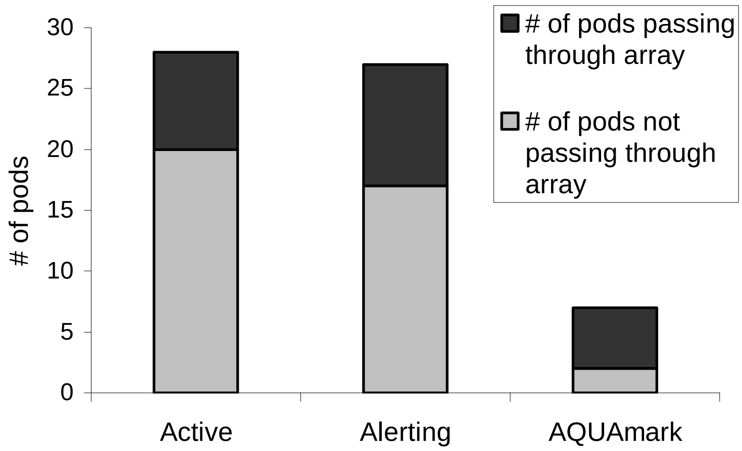

Figure 7. The figure shows the number of all pods coming within the experimental area that were passing and not passing through the array in the different treatments. A higher proportion of pods passed through the array during the aquamark treatment compared to the active treatment (Fishers' exact test, P=0.049).

4.3.3 Distribution analysis and closest approach distance

The overall distribution of *P. phocoena* in the experimental area did not change depending on the treatment used. The minimum approach distance in *aquamark* was however 10.38 m, larger than for both *active* and *alerting* which had 1.24 m and 1.13 m respectively. Figure 8 gives the frequencies of closest approaches in intervals within the experimental site. A total of 30 % of the pods during *aquamark* had their closest approach within 20 m of the pinger, and for *alerting* and *active* this was 25 and 35% respectively within the same range. The medians of the minimum approach distances were 28.12 m for *active*, 56.22 m for *alerting* and 35.85 m for *aquamark*.

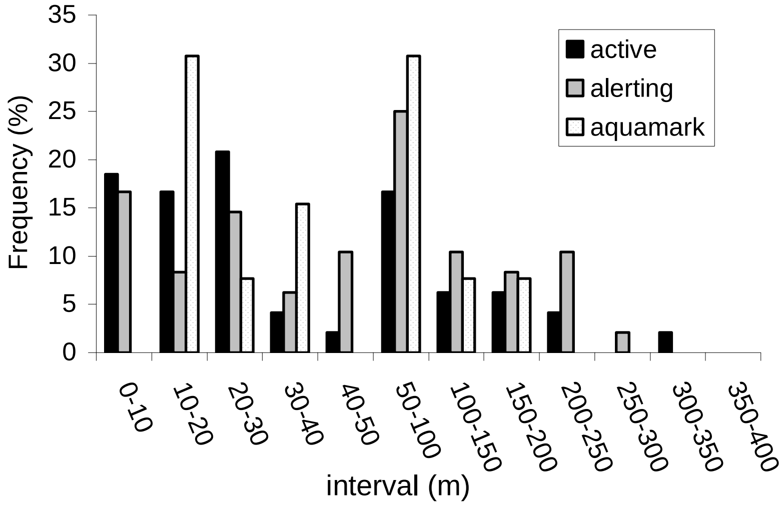

Figure 8. Frequency distribution of pods with the minimum approach distance to a pinger in the interval.

4.3.4 Observed swimming pattern around pinger array

Pods of different composition interacted with the interactive pinger in different ways. Figure 9a shows the distance to a pinger at each surfacing as well as the emissions of displacement sounds from the same pinger for a pod consisting of a mother and a calf (pod C), with the calf as focal animal. The same pod is followed from above in Figure 9b where the surfacings can be seen in relation to the pinger array. In Figures 10a and b, another mother and calf pair was tracked with the mother as focal animal (pod E), showing a different pattern. The calf in pod C triggered the pinger at a close distance. Whilst the pinger emitted the four beacon-mode displacement sounds the calf stayed close, and then retreated. The mother in pod E triggered the pinger when passing it. When the pinger was triggered again she stayed at a constant distance to it. Two pods of single animals (Figures 11a and b) triggered the pinger just prior to passing through the array and the displacement sounds were emitted whilst passing. In Figures 12a and b the porpoise swam along the south side of the array and passed through to the north side after the last beacon-mode displacement sound was emitted.

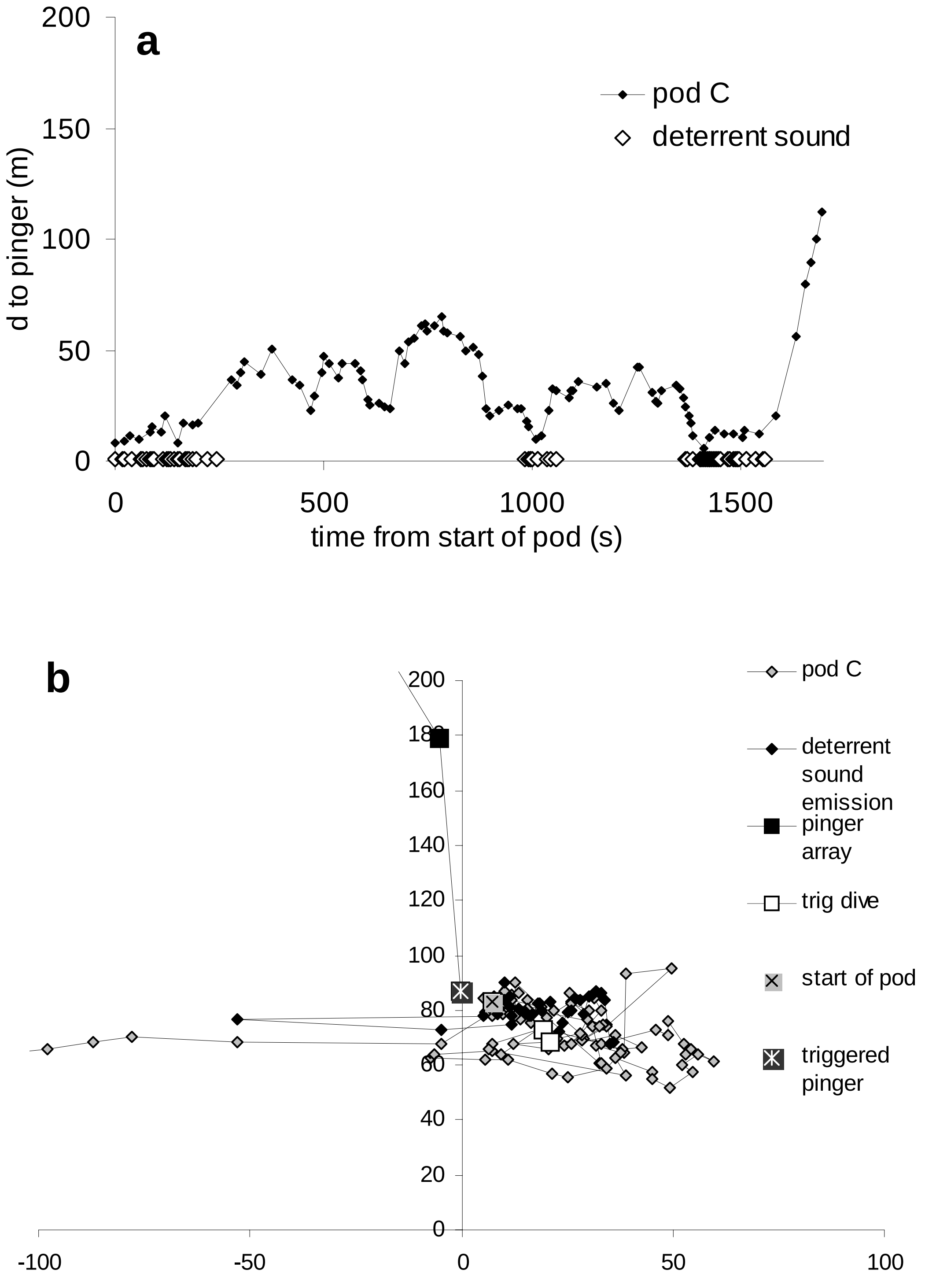

Figure 9. The figures show the surfacings of a pod of an adult mother and a calf, where the calf is the focal animal. a) The distance to a pinger for each surfacing and the emissions of deterrent sounds from the same pinger. b) The surfacings of the focal animal in relation to the pinger array. The theodolite observation station is positioned at (0,0). The values of the axes are in meters.

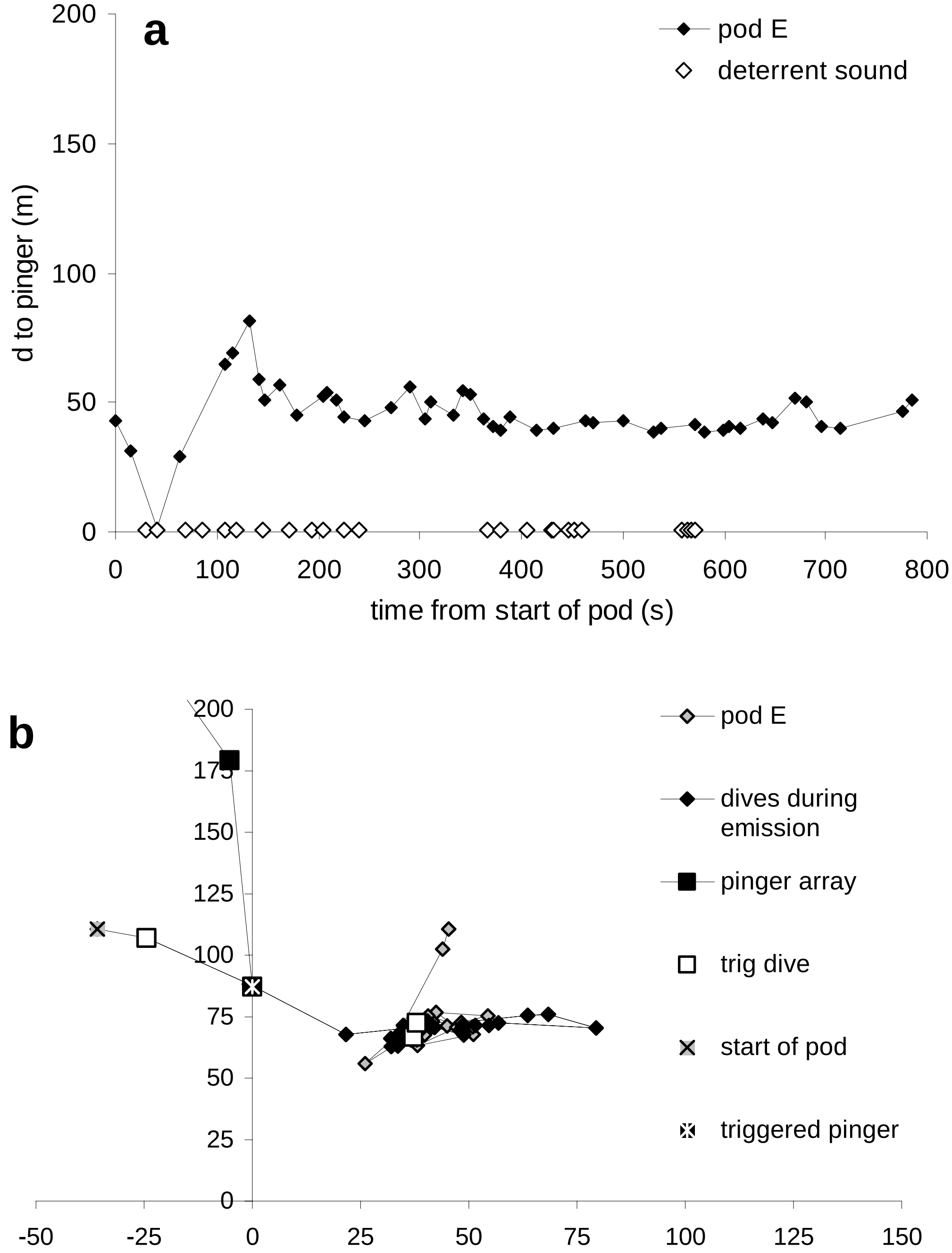

Figure 10. The figures show the surfacings of a pod of an adult mother and a calf, where the mother is the focal animal. a) The distance to a pinger for each surfacing and the emissions of deterrent sounds from the same pinger. b) The surfacings of the focal animal in relation to the pinger array. The theodolite observation station is positioned at (0,0). The values of the axes are in meters.

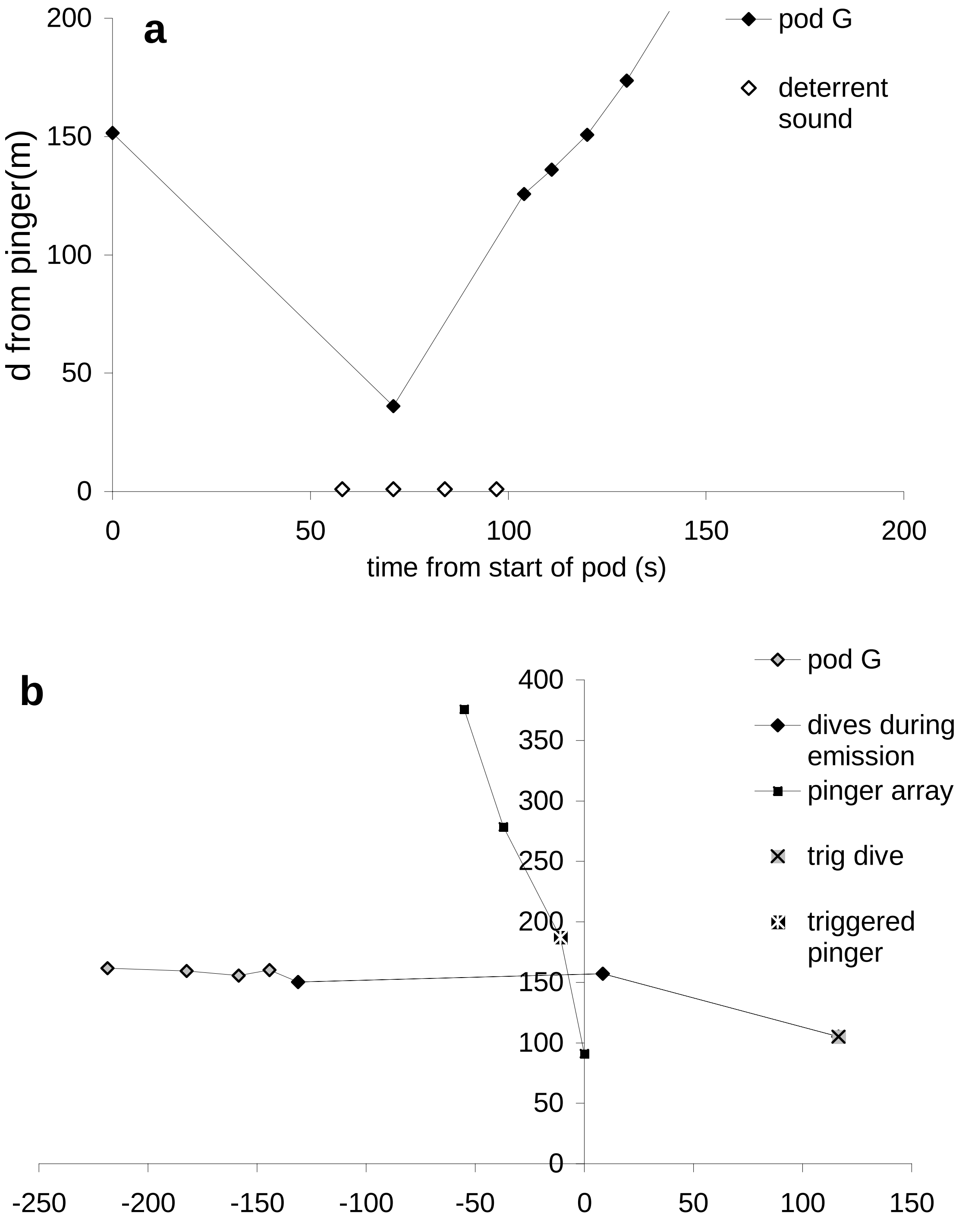

Figure 11. The figures show the surfacings of a pod of single adult animal. a) The distance to a pinger in each surfacing and the emissions of deterrent sounds from the same pinger. b) The surfacings in relation to the pinger array. The theodolite observation station is positioned at (0,0). The values of the axes are in meters.

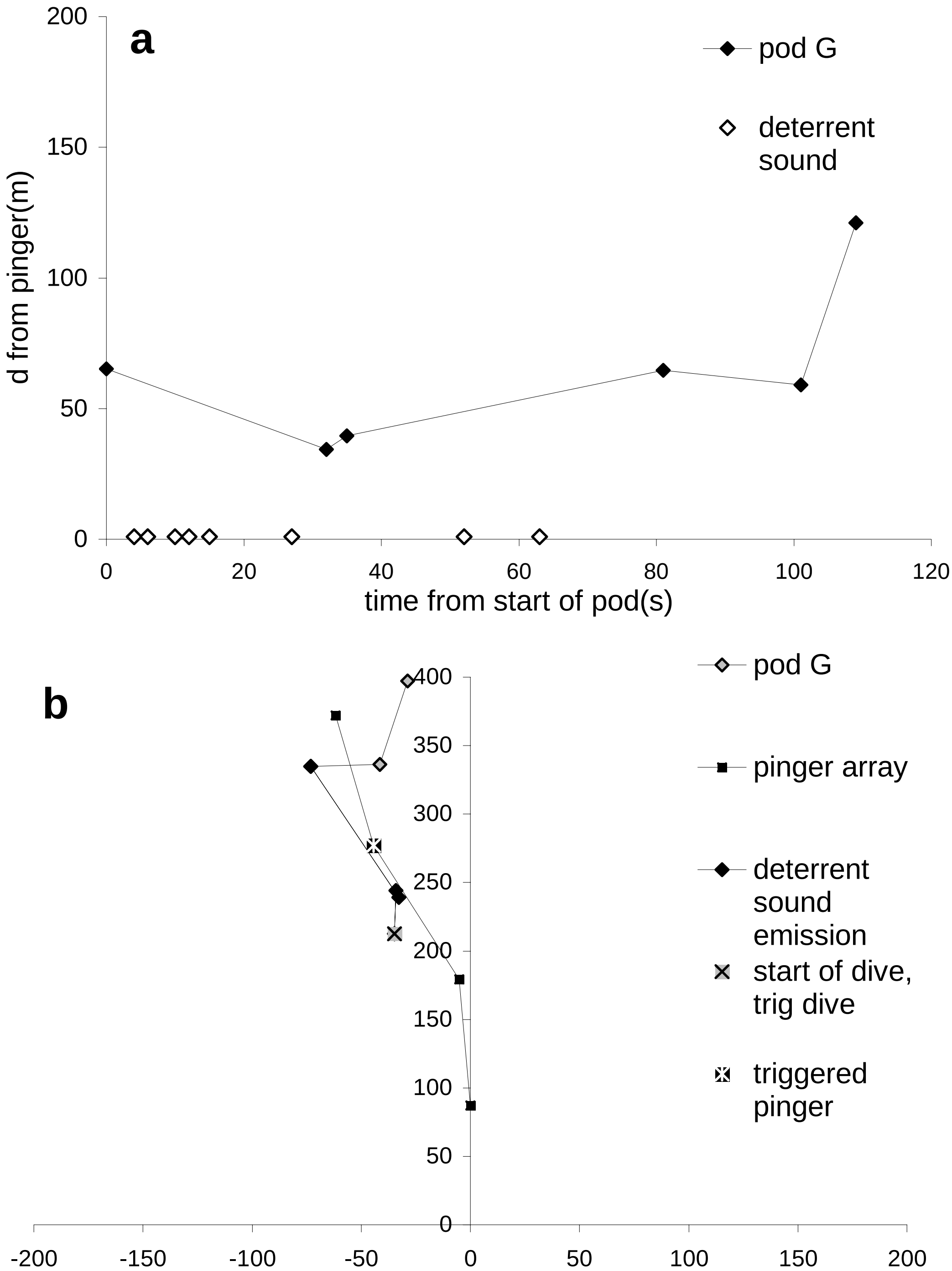

Figure 12. The figures show the surfacings of a pod of single adult animal. a) The distance to a pinger in each surfacing and the emissions of deterrent sounds from the same pinger. b) The surfacings in relation to the pinger array. The theodolite observation station is positioned at (0,0). The values of the axes are in meters.

5. Discussion

The results showed that *P. phocoena*, when first subjected to displacement sounds of the interactive pinger, stayed under the surface during the trig dive for a significantly longer time than for most other dives. Many times they could be heard, through a hydrophone, exploring the pinger acoustically with their sonar during this time, thus triggering the pinger subsequently. In the following two dives *P. phocoena* showed a clear avoidance reaction by swimming away from the pinger. After the initial displacement reactions, animals returned to their pre-trig behaviour and did not increase their distance to the pinger. An interesting and surprising result was that when the AQUA*mark* 100^{TM} pinger was used, porpoises passed in between pingers more often than when the interactive pinger was used.

5.1 Dive behaviour

When first subjected to displacement sounds of the interactive pinger *P. phocoena* showed a clear avoidance reaction by swimming away from the pinger in the two subsequent dives to the trig-dive (Figure 3a). This response was delayed and prolonged with one dive in comparison to the NAPER trials, where the reaction was seen already in the trig-dive and its subsequent dive (Poulsen 2004). In the previous NAPER trials with a single interactive pinger, an immediate but short-term displacement effect of the single emission of the pinger sound was observed on wild *P. phocoena* (Poulsen 2004). An avoidance reaction could be seen in the same dive as the pinger was triggered, a long duration dive covering a large distance (Poulsen 2004). The results in the present study are in concordance with the results from NAPER; however, the displacement effect was not immediate, but rather delayed and prolonged with one dive. Studies both in captivity (Kastelein et al. 2000, 2001) and in field trials (Cox et al. 2001 & Culik et al. 2001) have shown that *P. phocoena* try to avoid pinger sound sources. In some studies the displacement effect was so strong that *P. phocoena* was excluded from a greater area around nets with pingers. Culik et al. (2001) reported a closest approach of 130 m to an active beacon-mode pinger in a field trial, whereas both before and after the trial, individuals came as close as 4 and 8 m to the pinger. After the initial displacement reactions in the present study, animals returned to their pre-trig behaviour and did not increase their distance to the pinger. This supports the short-term displacement effect seen in the NAPER project (Poulsen 2004), as well as in studies of *P. phocoena* in captivity (Kastelein et al. 2000, 2001 & Lockyer et al. 2001).

The first trig-dive was of longer duration compared to most of the other dives in the first trig-series, and the dives in all the other treatments, but the animals were not swimming away from the pinger. What was occurring during this dive is not entirely known. Some of the pods turned towards and triggered the pinger once or several times more, without showing much avoidance reaction. Sometimes animals triggered multiple times when within just a few meters range of the pinger after it had been triggered. The animals were seemingly exploring the interactive pinger and supposedly the big underwater buoy keeping it in place. This buoy had strong target strength and would generate strong sonar echoes, a possible trait that stimulated the animals to investigate it further. This may be considered an artefact, since buoys of the size and target strength used here would not be present in a real fishery situation, where pingers will be attached to a net. In our case this arrangement was necessary to make it possible to deploy and haul the units on a daily basis and to ensure that wave action noise did not false trigger the device.

Kraus (1999) and Dawson (1994) hypothesised that pingers emitting sounds would stimulate *P. phocoena* to investigate its surroundings further. Even though Poulsen (2004) did not find this, it was confirmed by the present study. In some cases individual animals, mostly juveniles, returned to the pinger and triggered it again after the beacon-mode displacement sound cycle had ceased. Rather than enhancing the avoidance reaction that was present in the first encounter, the displacement effect became increasingly delayed. In the NAPER trials with a single pinger unit, repeated triggering was not encountered, and echolocation clicks were not heard after the displacement sound emission (Poulsen 2004). Hence, it was feared that *P. phocoena* would cease to echolocate in the area around the array. This was additionally based on the presumption that members of the suborder Odontoceti do not echolocate constantly, but may remain silent for some time (Barrett-Lennard 1996). However, most animals that came within the risk area were heard echolocating, and there was no difference in the amount between the treatments (acoustic data from NIPPER). Since *P. phocoena* triggered repeatedly it is reasonable to assume that the echolocating animals became aware of the float-line, and in reality hopefully also would discover the net. Whether the animals were aware enough to escape entanglement could not be determined with the present set-up because it was not possible to observe if they passed above or below the float line.

5.2 Avoidance of the pinger array

Phocoena phocoena was not excluded from an excessively large area around the pinger array. On the contrary, pods used the entire experimental area surrounding the pinger array in a similar fashion for all treatments. Pingers were approached at very close distances, and approximately 30 % of all pods had their closest approach within 20 m of the pingers. It was not surprising that *P. phocoena* came very close to the interactive pingers both in alerting and active state, considering that displacement sounds were only emitted when the pinger was triggered. A pod that came within the risk area during active treatment and did not trigger, despite echolocating, was excluded from analysis. This was based on a suspicion that the unit's trig function was not sensitive enough, rather than insufficient echolocation activity from the animal. Pods during the *aquamark* treatment were not expected to come as close as they actually did, since clear exclusion effects have been seen before in beacon-mode pinger trials, e.g. Culic et al. (2001).

During all treatments pods spent an equal, and fairly short, amount of time within the 50 m entanglement risk area. This indicates that even though the pods during the *aquamark* treatment came close to the pinger, they also seemed to pass through the area rather quickly. The pods during *alerting* and *active* treatment spent an equal amount of time within the risk area. Pods during the *active* treatment spent on average 70 % of the total time in the area after the pinger was triggered. This demonstrates that the displacement sounds emitted from the interactive pinger did not result in a startling response, or a forceful avoidance reaction.

Displacement sounds from either pinger did not stop animals from passing through the array of pingers. Some were even seen passing straight through the array under the influence of displacement sounds directly after triggering the pinger (Figure 11a, b). Another animal swam close and perpendicular to the array, triggered and passed through the array after the last beacon-mode displacement sound was emitted (Figure 12a, b).

During the *aquamark* treatment pods passed through the array more often than during the *active* treatment (P=0.049), but no differences were found for *active* and *alerting*. The lack of reaction to the AQUA*mark* 100™ pinger and the higher frequency of passages through the array were unexpected. Since it has been shown that AQUA*mark* 100™ used in commercial fishery trials reduces by-catch (Larsen 1997, Larsen et al. 2002a, b), the interactive pinger might be equally good at keeping an animal from getting entangled in a net as the traditional beacon-mode pinger. Whether these results mean that alerting sounds alone would be as good as the displacement sounds in reducing entanglement remains to be tested. In our study it has to be considered that rather few pods were tracked within the area during the *aquamark* treatment days, but still, most of these pods actually passed through the array.

During observations of *P. phocoena* in the study area certain behaviours were observed during all treatments. Some pods that did not pass through the array, instead passed between the inner-most buoy of the array and the coast or outside the outer-most end of the array. Some animals, mostly pairs of mother and calf, were fishing along and rather close to the shore. They passed slowly and sometimes stayed very close to the inner-most pinger buoy. Sometimes the calf, or mother, approached this pinger and triggered it without showing any obvious avoidance reactions (Figure 9a, b and 10a, b), but instead investigated the pinger further with its sonar. The same scenario was observed when the AQUA*mark* 100^{TM} pinger was used. Even though this pinger transmitted displacement sounds intermittently in beacon-mode, the animals did not seem much disturbed by it. Similar behaviours have been seen in a study by Cox et al. (2003) with *Tursiops truncatus* M (bottlenose dolphin), where animals appeared to be aware of the net, regardless of the status of pingers, and travelled just inshore or offshore of the buoys marking the ends of the net. They also stayed close to the net for longer periods of time, probably foraging. These results suggest that the response to pinger sounds, irrespective of pinger type, is not a pure displacement effect. It is rather an indication that the awareness of the net was increased. This could be sufficient for avoiding entanglement.

5.3 Habituation

Multiple triggering might be considered an indication of habituation to the displacement sounds emitted by the interactive pinger. The long term effectiveness of traditional beacon-mode pingers, possibly reduced by the effect of habituation, is a subject of concern that has been raised (Dawson et al. 1998, Cox et al. 2001). Studies have suggested that *P. phocoena* habituates to the sounds produced by pingers, however, normally after a longer period of time and with pingers that emit displacement sounds frequently (Cox et al. 2001). In order for habituation to take place in this study, with the very limited exposure of the displacement sounds (1-7% of the emissions from the AQUA*mark* 100^{TM} pinger), the same animals must have returned to the area year after year. This is not unlikely, however, in most cases the multiple triggering was done by calves, thus it is not probable that habituation has taken place. Studies on habituation has been conducted on traditional pingers that emit displacement sounds continuously, and where there will be a gradual increase in sound pressure level as animals come closer to the pingers. With the interactive pinger the displacement sound would come as a surprise at rather close distance. If habituation really occurred with the interactive pinger it might however not be completely detrimental. *Phocoena phocoena* might still use sounds of pingers as indicators of gillnets without being excluded from crucial habitats. It was not in the scope of this thesis to evaluate possible habituation between years and therefore we cannot draw any conclusions in the matter.

5.4 Future studies

As mentioned above it could not be determined in this study whether animals passing through the array did so under the float line, where they would have been entangled in gillnet, or safely above it, and neither if the simulated net was perceived as a barrier. Unfortunately there was some distance between the float line and the pinger array, and animals might already have passed the float line when triggering the pinger, as indicated by the very close approaches. This needs to be considered in future studies.

Another factor that needs to be evaluated is whether *P. phocoena* would pass through the array if one pinger would activate the row of pingers Displacement sounds did not hinder pods from passing through the array with this set up, not even with the conventional pinger emitting sounds continuously. This should prompt more behavioural studies, like the present one, also with traditional beacon-mode pingers, in order to obtain a better understanding of the real effect of the displacement sounds.

Further studies on the interactive pinger in large scale fishery trials are necessary to completely evaluate the by-catch reducing potential that it might have. It would also be interesting to use only the alerting sounds of the interactive pinger, since reactions in both *alerting* and *active* states were similar in this trial, and were evaluated to have approximately the same effect as the conventional AQUA*mark*100™ pinger. Further studies on these are in progress.

6. Conclusion

In conclusion, the most important effect of displacement sounds from both the interactive pinger and the AQUA*mark*100™ pinger might not be to displace *P. phocoena*, but to increase their awareness of the presence and location of nets. Since the interactive pinger transmits the same repertoire of displacement sounds as the AQUA*mark*100^{TM} pinger, that is known to reduce by-catch in commercial fisheries, it is assumed to have the same by-catch reducing effect. In addition, since it transmits much less displacement sounds, i.e. only when porpoises are in the vicinity of the nets, the interactive pinger should be considered a preferable environmental friendly mitigation alternative to the beacon-mode pingers currently on the market.

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8. References

Aguilar A & Borrell A (1995) Pollution and Harbour porpoises in the eastern North Atlantic: a review. pp 231-242 in: Bjørge A & Donovan GP (eds) Biology of the Phocoenids - Report of the International Whaling Commission, special issue 16, Cambridge.

Anonymous (2004) Council Regulation (EC) No 812/2004 of 26.4.2004 laying down measures concerning incidental catches of cetaceans in fisheries and amending Regulation (EC) No 88/98. Official Journal of the European Union L150/12-31.

ASCOBANS (1997) Resolution on incidental take of small cetaceans. Report of the second meeting of parties to ASCOBANS. Bonn, Germany.

Barrett-Lennard LG, Ford JKB & Heise KA (1996) The mixed blessing of echolocation: differences in sonar use by fish-eating and mammal-eating killer whales. Animal behaviour 51, 553–565.

Berggren P (1994) Bycatches of the harbour porpoise (*Phocoena phocoena*) in the Swedish Skagerrak, Kattegat and Baltic Seas; 1973-1993. pp 211–215 in: Perrin WF, Donovan GP & Barlow J (eds) Gillnets and cetaceans - Report of the International Whaling Commission, special issue 15, Cambridge.

Berggren P & Arrhenius F (1995) Sightings of harbour porpoises (*Phocoena phocoena*) in Swedish waters before 1990. pp 99-108 in: Bjørge A & Donovan GP (eds) Biology of the Phocoenids - Report of the International Whaling Commission, special issue 16, Cambridge.

Berggren P, Wade PR, Carlström J & Read AJ (2002) Potential limits to anthropogenic mortality for harbour porpoises in the Baltic region. Biological conservation 103, 313–322.

Cox TM, Read AJ, Solow A & Tregenza N (2001) Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? Journal of cetacean research and management 3, 81-86.

Cox TM, Read AJ, Swanner D, Urian K & Waples D (2003) Behavioural responses of bottlenose dolphins, *Tursiops truncatus*, to gillnets and acoustic alarms. Biological conservation 115, 203-212.

Culik BM, Koschinski S, Tregenza N & Ellis GM (2001) Reactions of harbor porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. Marine ecology progress series 211, 255–260.

Dawson SM (1991) Modifying gillnets to reduce entanglement of cetaceans. Marine mammal science 7, 274-282.

Dawson SM, Read A & Slooten E (1998) Pingers, porpoises and power: uncertainties with using pingers to reduce bycatch of small cetaceans. Biological conservation 84, 141-146.

Donovan GP & Bjørge A (1995) Harbour porpoises in the North Atlantic: edited extract from the report of the IWC scientific committee, Dublin

1995. pp 3-25 in: Bjørge A & Donovan GP (eds) Biology of the Phocoenids - Report of the International Whaling Commission, special issue 16, Cambridge.

Goodson AD, Klinowska M & Bloom PRS (1994) Enhancing the acoustic detectability of gillnets. pp 585-595 in: Perrin WF, Donovan GP & Barlow J (eds) Gillnets and cetaceans - Report of the International Whaling Commission, special issue 15, Cambridge.

Hammond PS, Berggren P, Benke H, Borchers DL, Collet A, HeideJørgensen MP, Heimlich S, Hiby AR, Leopold MF & Øien N (2002) Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of applied ecology 39, 361-376.

Heidejorgensen MP, Mosbech A, Teilmann J, Benke H, Schultz W (1992) Harbor porpoise (*Phocoena phocoena*) densities obtained from aerial surveys north of Fyn and in the Bay of Kiel. Ophelia 35, 133-146.

Frid C, Hammer C, Law R, Loeng H, Pawlak JF, Reid PC & Tasker M (2003) Environmental status of the European seas. Report to ICES (The International Council for the Exploration of the Sea).

Kastelein RA, Rippe HT, Vaughan N, Schooneman NM, Verboom WC & De Haan D (2000) The effects of acoustic alarms on the behavior of harbor porpoises (*Phocoena phocoena*) in a floating pen. Marine mammal science 16, 46-64.

Kastelein RA, de Haan D, Vaughan N, Staal C, & Schooneman NM (2001) The influence of three acoustic alarms on the behaviour of harbour porpoises (*Phocoena phocoena*) in a floating pen. Marine environmental research 52, 351-371.

Kinze CC (1994) Incidental catches of harbour porpoises (*Phocoena phocoena*) in Danish waters 1986–89. pp 183–188 in: Perrin WF, Donovan GP & Barlow J (eds) Gillnets and cetaceans - Report of the International Whaling Commission, special issue 15, Cambridge.

Koschinski S (2002) Current knowledge on harbour porpoises (*Phocoena phocoena*) in the Baltic Sea. Ophelia 55, 167-197.

Kraus SD, Read AJ, Solow A, Baldwin K, Spradlin T, Anderson E & Williamson J (1997) Acoustic alarms reduce porpoise mortality. Nature 388, 525.

Kraus SD (1999) The once and future ping: Challenges for the use of acoustic deterrents in fisheries. Marine technology society journal 33, 90-93

Larsen F (1997) Effekten af akustiske alarmer på bifangst av marsvin i garn. Danish Institute for Fisheries Research. Report 44–97.

Larsen F, Eigaard OR & Tougard J (2002a) Reduction of harbour porpoise by-catch in the North Sea by high-density gillnets. Report IWC/SC/54/SM30.

Larsen F, Vinther M & Krog C (2002b) Use of pingers in the Danish North Sea wreck net fishery. Report IWC/SC/54/SM32.

Lockyer C, Amundin M, Desportes G, Goodson D & Larsen L (2001) The tail of EPIC – Elimination of harbour Porpoise Incidental Catch. Report to the European Commission DG XIV 97/00006.

Lowry N & Teilmann J (1994) Bycatch and bycatch reduction of the harbour porpoise (*Phocoena phocoena*) in Danish waters. pp 203-209 in: Perrin WF, Donovan GP & Barlow J (eds) Gillnets and cetaceans - Report of the International Whaling Commission, special issue 15, Cambridge.

Mooney TA, Nachtigall PE & Au WWL (2004) Target strength of a nylon monofilament and an acoustically enhanced gillnet: Predictions of biosonar detection ranges. Aquatic mammals 30, 220-226.

Pence EA (1986) Monofilament gill net acoustic study. Contract report (40-ABNF-5-1988) to National marine mammal laboratory. Seattle, WA.

Poulsen LR (2004) The efficiency of an interactive pinger (activated by biosonar) - in displacing wild harbour porpoises, *Phocoena phocoena.* (M.Sc. thesis) Department of Zoophysiology, Institute of Biological Sciences, The University of Aarhus, DK.

Read AJ (2002) Potential mitigation measures for reducing the by-catches of small cetaceans in ASCOBANS waters. Report to ASCOBANS.

Read AJ & Westgate AJ (1997) Monitoring the movements of harbour porpoises (*Phocoena phocoena*) with satellite telemetry. Marine Biology 130, 315-322.

Tregenza NJC, Berrow SD, Hammond PS & Leaper R (1997) Harbour porpoise (Phococnea phocoena L.) by-catch in set gill-nets in the Celtic Sea. ICES Journal of marine science 54, 896-904.

Trippel EA, Strong MB, Terhune JM & Conway JD (1999) Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. Canadian journal of fisheries and aquatic sciences 56, 113-123.

Vinther M (1999) Bycatches of harbour porpoises (*Phocoena phocoena L.*) in Danish set-net fisheries. Journal of Cetacean Research Management 1, 123 - 135.

Appendix 1.

The table gives the characteristics of the repertoire of displacement sounds emitted by the AQ626 Interactive Pinger and AQUAmark 100™ pinger.

#	Displacement sounds
1	Single-up-sweep
2	Double-up-sweep
3	Single-down-sweep
4	Double-down-sweep
5	Up-down-sweep
6	Down-up-sweep
7	High frequency square tonal 85kHz
8	Low frequency square tonal 30kHz

The table gives the characteristics of the repertoire of the alerting sounds emitted by the AQ626 Interactive Pinger. Click train duration (ms) and the number of clicks per second (cps) in each click train.

#	Cps	Click train duration (ms)
1	50 – 200	540
2	50 – 100	265
3	25 – 200	525
4	25 – 100	235
5	50 – 500	1.040
6	50 – 1000	1.040
7	50 – 1000	2.350
8	50 – 2500	1.040