

Agenda Item 4.4.1: Review of progress in bycatch mitigation and report to MOP5

Differences in the response of a striped dolphin (*Stenella coeruleoalba*) and a harbour porpoise (*Phocoena phocoena*) to an acoustic alarm

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Secretariat's Note

The Secretariat would like to bring the following paper, submitted to ASCOBANS by R.A. Kastelein, to the attention of the Advisory Committee.



Differences in the response of a striped dolphin (*Stenella coeruleoalba*) and a harbour porpoise (*Phocoena phocoena*) to an acoustic alarm

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Received 11 March 2005; received in revised form 24 November 2005; accepted 25 November 2005

Abstract

Small cetacean bycatch in gillnet fisheries may be reduced by deterring odontocetes from nets acoustically. However, different odontocete species may respond differently to acoustic signals from alarms. Therefore, in this study a striped dolphin and a harbour porpoise were subjected simultaneously to sounds produced by the XP-10 experimental acoustic alarm. The alarm produced 0.3 s tonal signals randomly selected from a set of 16 with fundamental frequencies between 9 and 15 kHz, with a constant pulse interval of 4.0 s (duty cycle 8%) and a Source Level range of 133–163 dB re 1 μ Pa (rms). The effect of the alarm was judged by comparing the animals' respiration rate and position relative to the alarm during test periods with those during baseline periods. As in a previous study on two porpoises with the same alarm, the porpoise in the present study reacted strongly to the alarm by swimming away from it and increasing his respiration rate. The striped dolphin, however, showed no reaction to the active alarm. Based on harbour porpoise audiograms and the specific audiogram of the striped dolphin in the present study, and the low background noise levels during the experiment, both animals must have heard the alarm signals clearly. This study indicates that cetacean species are not equally sensitive to human-made noise disturbance. Therefore, source

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levels of acoustic alarms should be adapted to the species they are supposed to deter. In addition, alarms should be tested on each odontocete species for which they are intended to reduce bycatch. © 2005 Elsevier Ltd. All rights reserved.

Keywords: Alarm; Behaviour; Bycatch; Dolphin; Fisheries; Fishing; Gillnet; Odontocete; Pinger

1. Introduction

Many small odontocetes are accidentally caught in fishing nets and drown (Beddington, Beverton, & Lavigne, 1985; Bravington & Bisack, 1996; Lowry & Teilmann, 1994; Palka, Read, Westgate, & Johnston, 1996; Read & Gaskin, 1988; Trippel, Wang, Strong, Carter, & Conway, 1996). One potential way to reduce bycatch in gillnet fisheries is to deter the animals from the nets acoustically. Field studies with acoustic alarms on set gillnets have produced promising results with harbour porpoises (*Phocoena phocoena*; Barlow & Cameron, 2003; Gearin et al., 2000; Johnston & Woodley, 1998; Kraus et al., 1997; Laake, Rugh, & Baraff, 1998; Lien et al., 1995; Trippel, Strong, Terhune, & Conway, 1999) and some dolphins (Barlow & Cameron, 2003). In most of these field studies the number of animals caught was used as an indicator of the effect of the alarms tested, but the way in which the alarms affected the behaviour of the odontocetes was not investigated. Laake et al. (1998) and Culik, Koschinski, Tregenza, and Ellis (2001) showed that the porpoises actively avoided alarms in field experiments. Harbour porpoises and killer whales (*Orcinus orca*) were clearly displaced by Acoustic Harassment Devices (AHDs) used in fish aquaculture to keep pinnipeds away (Johnston, 2002; Morton & Symonds, 2002; Olesiuk, Nichol, Sowden, & Ford, 2002). Harbour porpoises are even deterred by low frequency playback of wind turbines (Koschinski et al., 2003) and by underwater data transmission sounds (Kastelein, Verboom, Muijsers, Jennings, & van der Heul, 2005). Much basic research is still needed in this area, especially in species other than harbour porpoises (Jefferson & Curry, 1996). Captive studies, in which the effects of various parameters of acoustic alarms on the behaviour of odontocetes can be studied in detail, have so far been conducted mainly on harbour porpoises (Kastelein, Goodson, Lien, & de Haan, 1995; Kastelein, de Haan, Goodson, Staal, & Vaughan, 1997; Kastelein et al., 2000; Kastelein, de Haan, Vaughan, Staal, & Schooneman, 2001).

Not all odontocete species react to underwater sounds in the same way. Field studies with the Dukane NetMark 1000 alarm, which clearly does have a deterring effect on harbour porpoises (Kastelein et al., 2000) and probably on tucuxi (*Sotalia fluviatilis*; Monteiro-Neto et al., 2004), suggest that some other odontocete species such as the Indo-Pacific humpback dolphins (*Sousa chinensis*) in South Africa and the bottlenose dolphin (*Tursiops truncatus*) showed little or no response to the alarm (Shanan Atkins, pers. comm.; Cox, Read, Swanner, Urian, & Waples, 2003).

When a stranded, rehabilitated striped dolphin (*Stenella coeruleoalba*) became available, housed with a harbour porpoise in a floating pen, the opportunity arose to study behavioural differences in the response of the two odontocete species to the same acoustic alarm. The most effective alarm tested so far on harbour porpoises in captivity was the XP-10 experimental alarm produced by the Dukane company (Kastelein et al., 2001). The randomised signal spectra produced by this alarm made it unpredictable to the animals. The aim of the present study was to discover whether this alarm, which was effective

in deterring two harbour porpoises in a previous study (Kastelein et al., 2001), was also effective in deterring another porpoise and the striped dolphin.

2. Materials and methods

2.1. Study animals

The study was carried out on a female striped dolphin and a male harbour porpoise that had been rehabilitated in the Netherlands. The female striped dolphin (code ScSH001) had stranded on the coast of the Netherlands in December 1997, at the estimated age of 3 (based on body length: 184 cm) or 4 years (based on body weight: 62 kg; Di-Méglio, Romero-Alvarez, & Collet, 1996). At the time of the study, the animal was estimated to be 4 or 5 years old, and had a body weight of 67 kg, a body length of 192 cm, and a girth anterior to the pectoral fins (at the auditory meatus) of 91 cm. The male porpoise (PpSH048) had stranded on the Island of Rottmerplaat, The Netherlands in February 1998, at the estimated age of 1.5 years. At the time of the study he was healthy, approximately 2 years old, weighed 27 kg and was 123 cm long.

The animals were fed six times a day: at 0900, 1015, 1130, 1330, 1515 and 1630 h. The diet of the striped dolphin consisted of herring (*Clupea harengus*) and that of the porpoise of herring and sprat (*Sprattus sprattus*).

2.2. Study area

The animals were housed in a floating pen (34 m × 20 m; 2.4 m deep at the sides and 2.8 m deep in the centre, containing two smaller pens; Fig. 1). The surrounding pontoons (plywood boxes filled with Styrofoam and coated with fibreglass) were submerged by about 10 cm. The bottom panel of the net was made of nylon and the four side panels were made of polypropylene. Both types of net had a stretched mesh size of 9 cm and a twine diameter of 3 mm. The net was covered with algae, barnacles and shellfish. Seawater could flow through the pen as could small fish and jellyfish.

The pen was in a harbour in the Southwest Netherlands, at Neeltje Jans (51°37'N, 03°40'E). The harbour is horseshoe-shaped (500 m × 280 m) with the entrance towards the north-east, and near the middle of the leeward side of the Oosterschelde surge barrier. The barrier is only closed during exceptionally high tides and storms and was open at the time of the study. Therefore the tidal amplitude inside the harbour was similar to that in the nearby North Sea (± 2.5 m). No shipping occurred within 2 km of the study area during the study. The depth of the harbour around the pen depended on the tide (Fig. 1). The bottom below the pen was smooth and covered with sandy silt. The salinity in the pen varied between 3.4‰ and 3.6‰. During the study the underwater visibility (as determined from a Secchi disc reading) was between 1.1 and 4.8 m, and the average monthly water temperatures were 17.7 °C in September and 14.7 °C in October. During the experiments both animals were kept in the main pen (Fig. 1).

2.3. Acoustic recording and analysis equipment

The Sound Pressure Levels (SPLs in dB re 1 μ Pa, rms) of the alarm were measured by using a hydrophone (Brüel and Kjaer, type 8101) connected via a 30 m extension cable

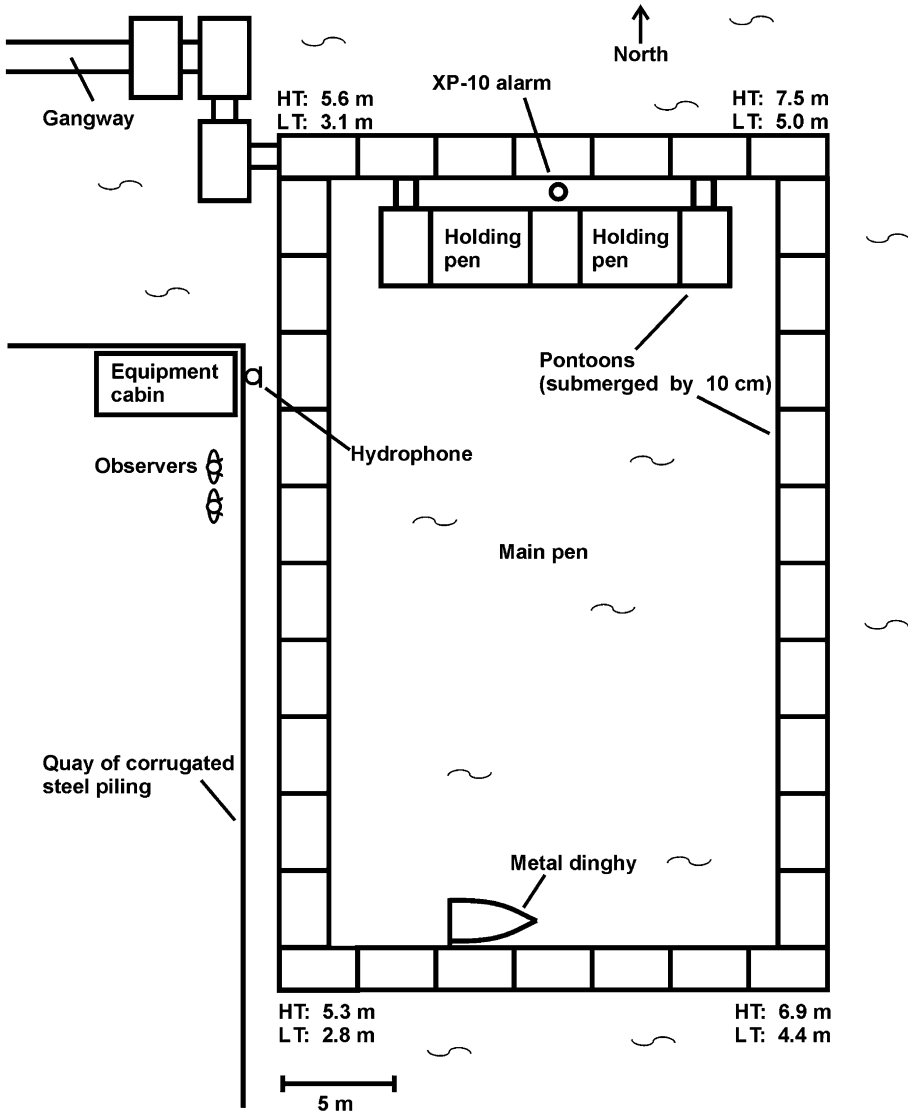


Fig. 1. Top view of the study area, showing the locations of the alarm, hydrophone, observers, and water depths at the corners of the floating pen at high tide (HT) and low tide (LT).

(Brüel and Kjaer) to a conditioning amplifier (Brüel and Kjaer, Nexus type 2690). The amplifier output was connected via a coaxial module (National Instruments, BNC-2090) to a computer (Dell, type XPS D200) with a data acquisition card (National Instruments, type PCI-MIO-16E-1) on which signals were sampled with a scan rate of 800 kHz, at 12 bits resolution. Monitoring, recording and analysis of signals were accomplished by the use of software modules developed by RIVO-DLO (National Instruments, Labview 4.1). A pistonphone (Brüel and Kjaer, type 4223) was used as a reference to calibrate the hydrophone, the conditioning amplifier and the analogue-to-digital conversion. The

reference data were logged separately and used in the analysis module to calculate the SPL. The fast Fourier transform (FFT) analysis covered a bandwidth of 20 Hz to 400 kHz. The FFT analysis was carried out over the complete pulse duration with a uniform window, a block size of 240,000 samples and a frequency resolution of 3.3 Hz. All SPLs reported here are corrected for the response curves of the hydrophone, the amplifier and analogue-to-digital conversion. To avoid near-field effects, the Source Level (SL) of the alarm was calculated from SPL recordings made at a distance of 2 m from the alarm, at a depth of 1.5 m (the depth of the alarm).

2.4. Underwater background noise

The equipment used to measure the background noise consisted of a hydrophone (Brüel and Kjaer, 8101), a voltage amplifier system (TPD, 0–300 kHz), and an analyser system (Hewlett–Packard, 3566, controlled by a Toshiba notebook computer; 0–100 kHz, sample frequency 260 kHz, line distance 32 Hz, FFT analysis with Hanning filter). The total system was calibrated with a pistonphone (Brüel and Kjaer, 4223) and a white noise insert voltage signal into the hydrophone pre-amplifier. The L_{eq} -method (equivalent sound pressure level; Hassall & Zaveri, 1988) was used to determine the time-averaged noise level in the pen. The measurement duration was 32 s. The result was corrected for the frequency sensitivity of the hydrophone and the characteristics of the measurement equipment. Background noise measurements were carried out under calm weather conditions (sea state 2, Fig. 2).

2.5. Acoustic alarm

The NetMark XP-10 experimental alarm was manufactured by the Dukane Corporation, St. Charles, Ill., USA, to investigate whether randomly-varying signals would be more effective in deterring odontocetes than the predictable signals produced by the NetMark 1000 alarm that was commercially available until around the year 2000 (several other manufacturers currently produce alarms with similar acoustic parameters). The XP-10 alarm produced 16 different tonal signals in the range of 9–15 kHz, generated in random order (this was done with a shift register, 16 bits in length, so that eventually a sequence was repeated after 65536 cycles). The pulse duration (0.3 s) and pulse interval

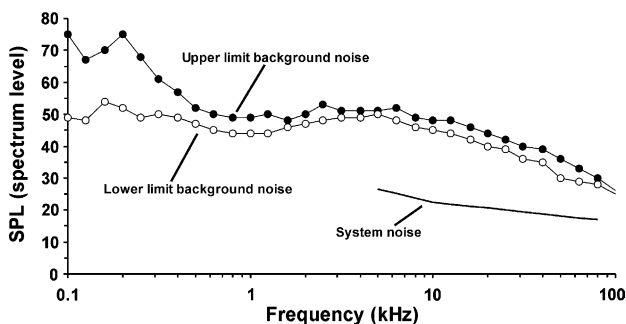


Fig. 2. Background noise limits in the floating pen between 100 Hz and 80 kHz. Also shown is the system noise, which did not influence the measurements. Results are given as equivalent spectrum levels in dB re $1 \mu\text{Pa}/\sqrt{\text{Hz}}$, at 1/3-octave centre frequencies.

(4.0 s) were constant. The duty cycle was 8%. The alarm produced significant harmonic energy, especially in the odd harmonics. The frequency spectra of one of the 16 signals, recorded at 2 m from the alarm and in the general surfacing area of the porpoise during test periods, which was similar to those in this study, is given by Kastelein et al. (2001). Taking all 16 signals into account, the power averaged SL was 145 dB re 1 μ Pa at 1 m (all SLs are given in dB re 1 μ Pa, rms), the lowest level of the fundamental frequency was 133 dB at 9 kHz, and the highest level of the fundamental frequency was 163 dB at 14 kHz. In signals between 9 and 11 kHz the third harmonic dominated the spectrum and was 10–20 dB higher than the level of the fundamental frequency. In signals above 11 kHz the fundamental frequency contained more energy than the harmonics.

The highest SPL of the fundamental frequency at the usual surfacing area of the porpoise when the alarm was active (the end of the pen furthest from the alarm) was 133 dB at 13 kHz, while the lowest fundamental SPL was 116 dB at around 11 kHz. The highest harmonic level was 138 dB in the third harmonic of the 11 kHz signal. Above 75 kHz, harmonic energy was still present and in some cases significant. Due to the shallow water propagation conditions, causing alternating effects of reflections, and the alarm's transducer characteristics, the SPLs of each of the 16 signal types varied by up to 10 dB.

To allow remote activation of the alarm it was provided with an external power supply producing 6 V at the alarm end of the cable. The sound was produced omni-directionally in the horizontal plane, but slightly flattened in the vertical direction due to the cylindrical transducer element and the air cavity at the top of the alarm. The red polyurethane housing of the alarm had a diameter of 5 cm, was 14 cm long and weighed 280 g without batteries. A 450 g piece of lead, hanging from a rope below the alarm, kept it vertically stable at 1.5 m below the water surface in the middle of the northern end of the pen (Fig. 1).

2.6. *Experimental procedures*

The inactive alarm was put into position several hours before each session started. Because of the effect of the alarm was expected to be strong, it was not placed on the southern end of the pen, as the agitated/frightened animals might have injured themselves against the sharp edges of the small pens that floated in the main pen (Fig. 1).

Each session was composed of a 15 min baseline period (alarm inactive), followed immediately by a 15 min test period (alarm active). One session was conducted per day between 16.45 and 17.15 h. During sessions, people were not allowed on the pontoons. Sessions were carried out on 18 days under calm weather conditions between 23 September and 12 October 1998. Sessions were not carried out during rainfall or when wind speeds were above force 4 on the Beaufort Scale.

An underwater listening system was used to check whether the alarm was operating and to monitor the audible part of the underwater background noise during the test sessions. The system was composed of a hydrophone (LabForce 1 BV, model 90.02.01), a charge pre-amplifier (Brüel & Kjaer, 2635) and an amplified loudspeaker. The hydrophone was placed 1 m below the water surface on the west side of the pen (Fig. 1).

2.7. *Response variables and behavioural data recording*

The distance between the inactive alarm and the general swimming area of the animals, and the distance between the active alarm and the general swimming area, were used to

indicate the effectiveness of the alarm in keeping animals away from fishing nets. The number of respirations during the sessions was used as an indicator of the level of agitation of an animal.

During the baseline and test periods, the locations where each animal surfaced were plotted on a map of the pen by two observers. The observers were, depending on the tide, 2–4.5 m above water level on land, to the west of the pen (Fig. 1). On most days, the animals could be seen up to 1 m below the water surface, but on some days the water was so clear that the observers could see the bottom of the pen. Since on those days the animals were generally not seen swimming far away from their surfacing locations, it was assumed that the locations where they respired indicated their general swimming area.

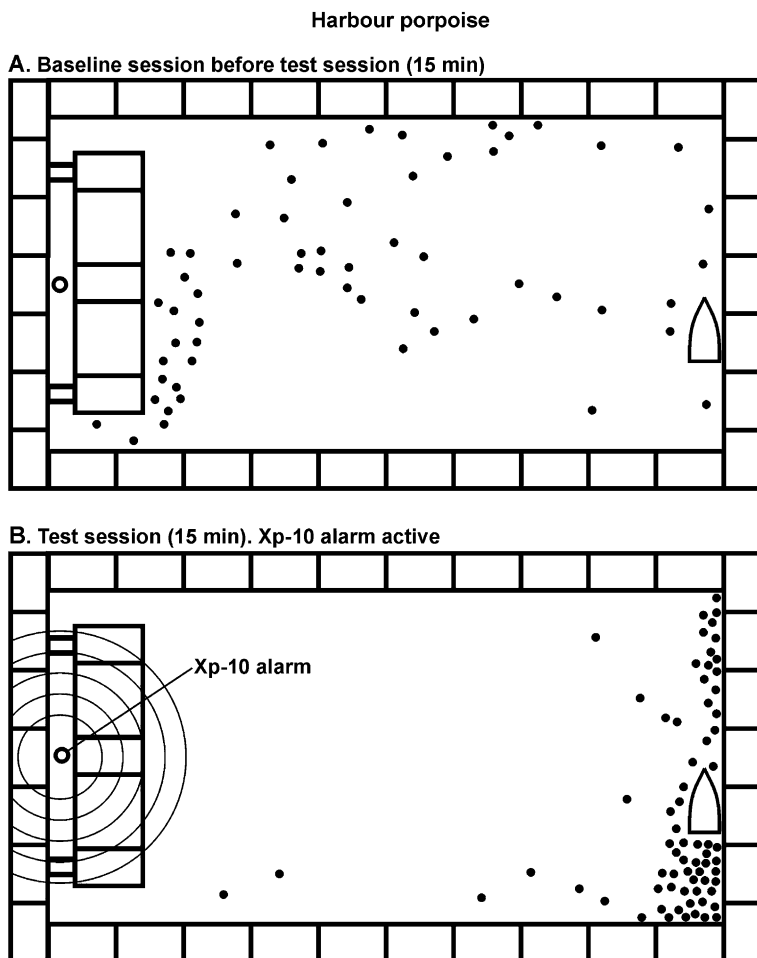


Fig. 3. A map from a typical session with the XP-10 experimental alarm, showing where the harbour porpoise surfaced during the 15 min baseline (A) and test periods (B) as dots. Note the large displacement and the larger number of surfacings (respirations) during the test period. This is the same session as the one shown for the striped dolphin in Fig. 4.

From the maps, the following response variables were derived: the number of respirations (or surfacings), and the distances between the alarm and the surfacings during baseline and test periods. The following subjective general behavioural data were also recorded for the test period (levels are relative to the preceding baseline period): swimming depth (normal or shallow), swimming speed (slow, normal or fast), and respiration force (normal or strong).

2.8. Statistical analysis

Statistical analysis was done on Minitab release 13 (Ryan & Joiner, 1994) with a significance level of 0.05. Data screening showed that the assumptions of analysis of covariance (ANCOVA; normality of residuals and homogeneity of variances, see Zar, 1999) were met,

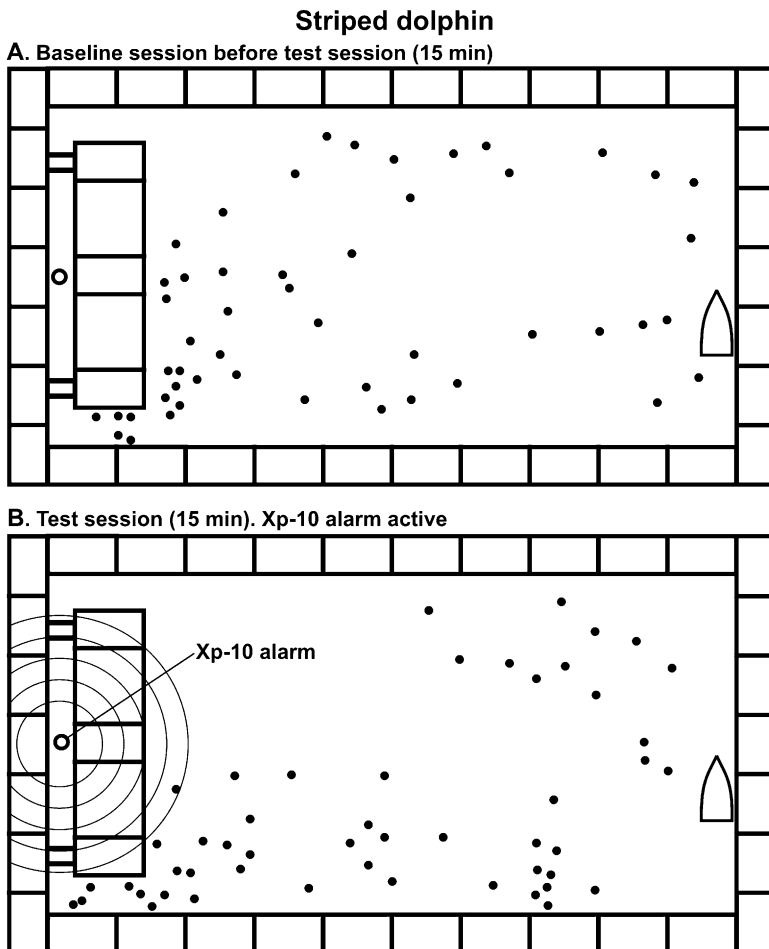


Fig. 4. A typical map from a session with the XP-10 experimental alarm, showing where the striped dolphin surfaced during the 15 min baseline (A) and test periods (B) as dots. Note the lack of effect during the test period. This is the same session as the one shown for the harbour porpoise in Fig. 3.

and that the environmental parameters (tide, underwater visibility, water temperature, and salinity) had little or no effect on the response variables, so these parameters were not included in the analysis. A separate ANCOVA was used to test the effect of the alarm (factor: period, levels: baseline and test) on each response variable (distance from alarm and number of respirations) for each animal. Therefore, four ANCOVAs were carried out in all. The session number was included in each ANCOVA as the covariate, so that any effect of session number could be both quantified and corrected for before the analysis of the factor (Zar, 1999).

3. Results

The harbour porpoise responded to the alarm's sound (during the test periods) by increasing its distance from the alarm and by increasing its number of respirations in

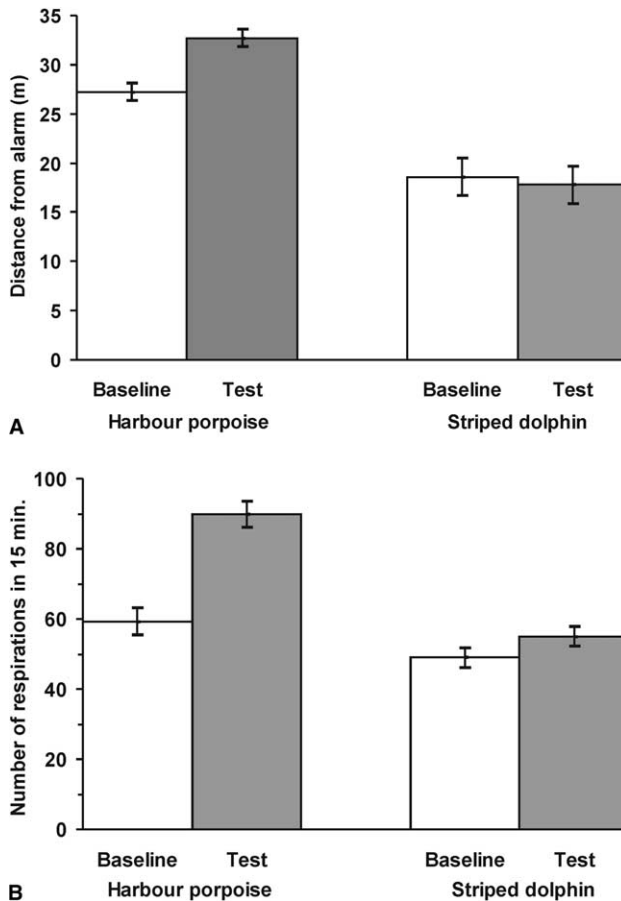


Fig. 5. The mean distances between the alarm and the surfacings of the harbour porpoise and striped dolphin during the 18 baseline and test periods (A; see Tables 1 and 3) and the mean number of respirations during the 18 baseline and test periods for the same animals (B; see Tables 2 and 4). All means are adjusted for the covariate session number. The bars indicate standard errors.

the test periods compared to the baseline periods (Figs. 3 and 5, Tables 1 and 2). For the number of respirations, there was a significant effect of session number: the porpoise increased its number of respirations during the 15 min test periods from about 50 in the beginning of the study to about 130 at the end of the study. The subjective behavioural data showed that during the test periods, the harbour porpoise swam faster and nearer to the surface and breathed more forcefully than during the baseline periods. No obvious decrease in effect of the alarm on the response variables or on the behavioural data was noticed within the 15 min test sessions.

In contrast to the harbour porpoise, the striped dolphin did not increase her distance from the alarm or increase her number of respirations in the test periods compared to the baseline periods (Figs. 4 and 5, Tables 3 and 4). The subjective behavioural data showed that during the test periods, the striped dolphin swam at similar speed and depth and breathed with similar force as during the baseline periods.

Table 1

ANCOVA on median distances of surfacings from the transducer by the harbour porpoise for the factor period (baseline or test) and covariate session number

Source of variation	Df	Adjusted MS	<i>F</i>	<i>P</i>
Period	1	271.7	20.2	<0.001
Session no. (covariate)	1	6.7	0.5	ns
Error	33	13.5		
Total	35			

Df: degrees of freedom, MS: mean squared, ns: not significant.

Table 2

ANCOVA on numbers of respirations by the harbour porpoise for the factor period (baseline or test) and covariate session number

Source of variation	Df	Adjusted MS	<i>F</i>	<i>P</i>
Period	1	8372.3	32.5	<0.001
Session no. (covariate)	1	2951.1	11.5	<0.005
Error	33	257.3		
Total	35			

Df: degrees of freedom, MS: mean squared.

Table 3

ANCOVA on median distances of surfacings from the transducer by the striped dolphin for the factor period (baseline or test) and covariate session number

Source of variation	Df	Adjusted MS	<i>F</i>	<i>P</i>
Period	1	5.7	0.1	ns
Session no. (covariate)	1	85.7	1.3	ns
Error	33	63.7		
Total	35			

Df: degrees of freedom, MS: mean squared, ns: not significant.

Table 4

ANCOVA on numbers of respirations by the striped dolphin for the factor period (baseline or test) and covariate session number

Source of variation	Df	Adjusted MS	<i>F</i>	<i>P</i>
Period	1	336.1	2.5	ns
Session no. (covariate)	1	2.0	0.0	ns
Error	33	135.4		
Total	35			

Df: degrees of freedom, MS: mean squared, ns: not significant.

4. Discussion and conclusions

4.1. Evaluation of the data

The porpoise's average distance from the alarm during the test periods was fairly constant (around 32 m); in most cases he swam as far away from the alarm as possible within the confinement of the 34 m long pen. In a larger pen, he may have moved further away from the alarm.

In the present study the alarm was switched on at the SL reported. This sudden onset may have startled the porpoise. In the wild, a marine mammal can swim freely towards a sound source, and may be able to regulate the speed with which the received SPL increases. However, in the present study the porpoise did not habituate to the sounds during the 15 min test sessions, and like in a similar study with porpoises, returned to baseline behaviour immediately after the sound ceased (Kastelein et al., 2000). This suggests that little of the behaviour of the animal observed during the 15 min test sessions can be ascribed to a 'startle' effect.

The present study was limited by animal welfare considerations. The animals were not exposed to the alarms' sounds for very long time periods to test potential habituation to the sounds, and the SL tested was limited by the maximum distance the animals could swim away from the alarms.

4.2. Potential reasons for the different effects of the alarm on the two odontocetes

The differences in response between the two odontocetes in the present study could be due one or more of the following reasons:

4.2.1. Individual differences

Only one animal per species was available for the present study. It is not clear how representative each study animal was for its species. Age, sex, location, and experience may influence the behaviour of individuals. In addition, the two study animals may have influenced one another. Also, the fact that no effect of the alarm was seen in the striped dolphin does not mean that there was no effect, only that no effect was detected with the methods used in the present study. However, the porpoise in the present study reacted similarly to the same XP-10 alarm as two other porpoises in the same floating pen and under the same environmental conditions (Kastelein et al., 2001). Therefore, we conclude that the reaction of the porpoise in the present study is representative of the species in this context. Because striped dolphins have almost never been kept in captivity, and no behavioral studies with

acoustic alarms in captivity have been conducted with this species, we cannot determine how representative the reaction of the animal in the present study is for its species.

4.2.2. Species differences in hearing

The response of an animal to an alarm not only depends on the exposure level, but also on the frequency spectrum of the sound in relation to the hearing threshold of the species for that frequency or frequency band, its critical bandwidth, and directivity index. Thus the SL of an alarm without information on the frequency spectrum is of little use in estimating its audibility. Odontocetes have U-shaped audiograms (Richardson, Greene, Malme, & Thomson, 1995), and therefore may be more sensitive to the higher frequency harmonics of an alarm than to the lower fundamental frequency.

Apart from the exposure level and hearing characteristics of an animal, the spectral background noise level can also play a role in the detection and effect of a sound. Comparison of the alarm's 16 spectra at the animals' swimming areas when the alarm was active with the porpoise and striped dolphin audiograms (Kastelein, Bunskoek, Hagedoorn, Au, & de Haan, 2002, 2003), suggests that most of the spectrum of the alarm was audible to both the porpoise and the striped dolphin in the entire pen (Fig. 6). The audiogram of the striped dolphin (Kastelein, Hagedoorn, Au, & de Haan, 2003) was of the animal in the present study, and is believed to be normal, as it resembles the audiogram of the bottlenose dolphin (Johnson, 1967). The hearing of the harbour porpoise was not tested, but is thought to be normal for the species, as the animal reacted similarly to

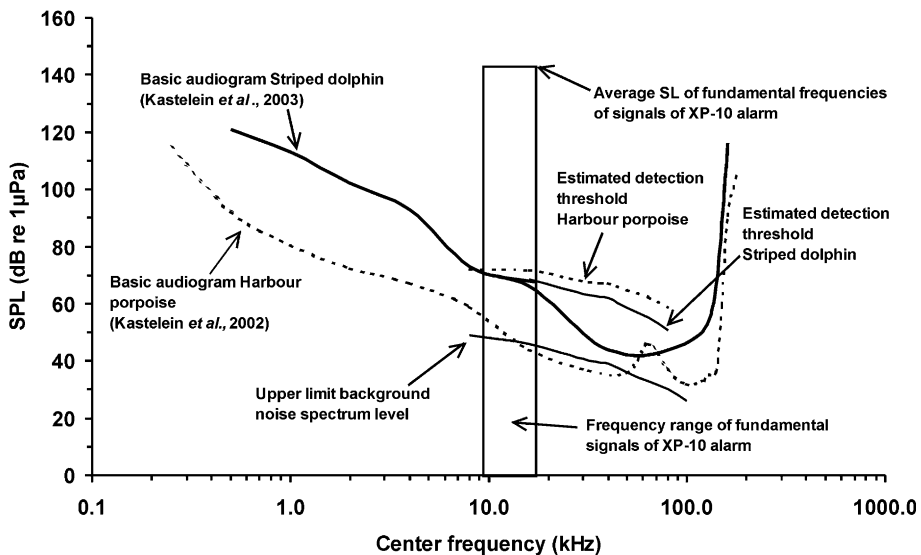


Fig. 6. The basic underwater audiograms (mean 50% detection thresholds; sound pressure level (SPL) in dB re 1 μ Pa) of the striped dolphin in the present study and a harbour porpoise for narrow-band FM signals (Kastelein et al., 2002, 2003) obtained with the same equipment, very similar methodology, in the same study area, and during overlapping study periods. The bar shows the frequency range and average source level (SL) of the 16 fundamental frequencies of the XP-10 experimental alarm. Also shown is the upper limit of the background noise and the estimated detection thresholds of the harbour porpoise and the striped dolphin for the XP-10 signals (for calculations see the "Discussion" section).

the sounds of the same acoustic alarm as porpoises in a previous study in the same floating pen (Kastelein et al., 2001). Fig. 6 shows the estimated detection threshold levels for both species [Detection threshold = Background noise + Critical ratio – Directivity index], based on the upper level of the background noise in the pen (Fig. 2), an estimated critical ratio for cetaceans (based on Johnson, McManus, & Skaar, 1989 and Au & Moore, 1990) and the receiving directivity indexes for bottlenose dolphins and harbour porpoises (Au & Moore, 1984; Kastelein, Janssen, Verboom, & de Haan, 2005). Above 10 kHz, the harbour porpoise detection threshold is considerably higher than the audiogram threshold. Because the hearing of the striped dolphin was less sensitive than that of harbour porpoises, its detection threshold around 10 kHz was roughly equal to its audiogram threshold. Above 20 kHz her audiogram threshold was below the detection threshold. Nevertheless, under these background noise conditions, the SPLs of the alarm sounds were considerably above the detection thresholds, so the alarms were very well audible to both animals and background noise did not influence the results.

When audible, the SPL of a sound received by animals probably plays a role in whether sound is perceived as a threat or as an interesting novelty. Kastelein et al. (1995) describe two juvenile male harbour porpoises in a small concrete pool that responded strongly (by increased swimming speed and respiration rates) to an acoustic alarm, but little response was elicited from a female harbour porpoise when the same alarm was offered in a larger floating pen (Kastelein et al., 1997).

4.2.3. Species differences in behaviour

Not all animal species are frightened equally easily. The need to flee from a sound may depend on the animal's perceived chances of being preyed. Odontocete species react differently to underwater sounds. The harbour porpoise is a solitary odontocete. Single adult animals are taken by predators such as sharks and killer whales (*Orcinus orca*). It is a coastal species which avoids engine-driven boats (Amundin & Amundin, 1973; Polacheck & Thorpe, 1990). In contrast, species such as the striped dolphin, common dolphin (*Delphinus delphis*), and whitebeaked dolphin (*Lagenorhynchus albirostris*) approach fast-moving power vessels and even ride on their bow waves or wakes. These are generally open water species, which usually occur in groups. In the wild they may be less susceptible to predation due to their larger size and the deterring effect of the group. By swimming in the bow wave or wake of ships, these species subject themselves to high sound pressure levels. However, ships create broadband noise, so bow-riding dolphins are subjected to a high overall broadband noise level, but not to high spectrum levels (especially not when the spectrum is 'weighted' by the inverse shape of the audiogram). Furthermore, dolphins swim mainly in the acoustic near field of the ship where levels are considerably lower than in the far field (W.C. Verboom, pers. obs.).

It is difficult to determine whether differences in reaction to sound are due to hearing differences or differences in behaviour in relation to sound, unless two species have similar hearing.

4.3. Suggestions for future research

If the behaviour of the striped dolphin in the present study is representative for its species, then not all odontocete species can be deterred from fishing nets with acoustic alarms that have similar acoustic characteristics as the experimental alarm that was used in the

present study. As a consequence, any alarm should be tested on the target odontocete species before being used on a large scale. Gaining more fundamental knowledge on the hearing and behaviour in relation to sound of odontocete species is important in finding and enhancing acoustic methods of reducing bycatch in fishing nets.

Acknowledgements

We thank Rob Triesscheijn, Helmi ter Horst, L. Tillema and Lydia de Boer for their assistance with data collection and analysis. We thank Ken Neltner (Dukane Company, St. Charles, IL, USA) for providing the experimental Dukane alarm for this project. We thank Anne Collet and her stranded cetacean recovery team for her efforts in saving the striped dolphin twice. Without her this study would not have been possible. This project was funded by the Sea Mammal Research Company (Seamarco), and the North Sea Directorate (DNZ; through Wanda Zevenboom, contract number: 76/317581, IBO14.1, 1999) of the Directorate-General of the Netherlands Ministry of Transport, Public Works and Water Management (RWS). The study was conducted under authorisation of the Netherlands Ministry of Agriculture, Nature Management and Fisheries, Department of Nature Management. Endangered Species Permit FEF27 06/2/98/0184.

References

- Amundin, M., & Amundin, B. (1973). On the behaviour and study of the harbour porpoise (*Phocoena phocoena*) in the wild. In G. Pilleri (Ed.). *Investigations on Cetacea* (Vol. 5, pp. 317–328). Bern: Hirnanatomisches Institut.
- Au, W. W. L., & Moore, P. W. B. (1984). Receiving beam patterns and directivity indices of the Atlantic bottlenose dolphin *Tursiops truncatus*. *Journal of the Acoustical Society of America*, *75*, 255–262.
- Au, W. W. L., & Moore, P. W. B. (1990). Critical ratio and critical bandwidth for the Atlantic bottlenose dolphin. *Journal of the Acoustical Society of America*, *88*, 1635–1638.
- Barlow, J., & Cameron, G. A. (2003). Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. *Marine Mammal Science*, *19*, 265–283.
- Beddington, J. R., Beverton, R. J. H., & Lavigne, D. M. (1985). *Marine mammals and fisheries*. London: George Allen & Unwin.
- Bravington, M. V., & Bisack, K. D. (1996). *Estimates of Harbour Porpoise Bycatch in the Gulf of Maine Sink Gillnet Fishery, 1990–1993*. Report of the International Whaling Commission, Vol. 46, pp. 567–574.
- Cox, T. M., Read, A. J., Swanner, D., Urian, K., & Waples, D. (2003). Behavioral responses of bottlenose dolphins, *Tursiops truncatus*, to gillnets and acoustic alarms. *Biological Conservation*, *115*, 203–212.
- Culik, B. M., Koschinski, S., Tregenza, N., & Ellis, G. M. (2001). Reactions of harbor porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. *Marine Ecology Progress Series*, *211*, 255–260.
- Di-Méglio, N., Romero-Alvarez, R., & Collet, A. (1996). Growth comparison in striped dolphins, *Stenella coeruleoalba*, from the Atlantic and Mediterranean coasts of France. *Aquatic Mammals*, *22*, 11–21.
- Gearin, P. J., Gosho, M. E., Laake, J. L., Cooke, L., DeLong, R. L., & Hughes, K. M. (2000). Experimental testing of acoustic alarms (pingers) to reduce bycatch of harbour porpoise, *Phocoena phocoena*, in the state of Washington. *Journal of Cetacean Research and Management*, *2*, 1–9.
- Hassall, J. R., & Zaveri, K. (1988). *Acoustic noise measurements*, Brüel & Kjaer documentation.
- Jefferson, T. A., & Curry, B. E. (1996). Acoustic methods of reducing or eliminating marine mammal-fishery interactions: do they work?. *Ocean and Coastal Management* *31*, 41–70.
- Johnson, S. C. (1967). Sound detection thresholds in marine mammals. In W. N. Tavolga (Ed.). *Marine bioacoustics* (Vol. 2, pp. 247–260). New York: Pergamon.
- Johnston, D. W. (2002). The effect of acoustic harassment devices on harbour porpoises (*Phocoena phocoena*) in the Bay of Fundy, Canada. *Biological Conservation*, *108*, 113–118.
- Johnson, S. C., McManus, M. W., & Skaar, D. (1989). Masked tonal thresholds in the belukha whale. *Journal of the Acoustical Society of America*, *85*, 2651–2654.

- Johnston, D. W., & Woodley, T. H. (1998). A survey of acoustic harassment device (AHD) use in the Bay of Fundy, NB, Canada. *Aquatic Mammals*, 24, 51–61.
- Kastelein, R. A., Bunschoek, P., Hagedoorn, M., Au, W. W. L., & de Haan, D. (2002). Audiogram of a harbor porpoise (*Phocoena phocoena*) measured with narrow-band frequency-modulated signals. *Journal of the Acoustical Society of America*, 112, 334–344.
- Kastelein, R. A., Goodson, A. D., Lien, J., & de Haan, D. (1995). The effects of acoustic alarms on Harbour porpoise (*Phocoena phocoena*) behaviour. In P. E. Nachtigall, J. Lien, W. W. L. Au, & A. J. Read (Eds.), *Harbour porpoises, laboratory studies to reduce bycatch* (pp. 157–167). Woerden, The Netherlands: De Spil Publishers.
- Kastelein, R. A., de Haan, D., Goodson, A. D., Staal, C., & Vaughan, N. (1997). The effects of various sounds on a harbour porpoise (*Phocoena phocoena*). In A. J. Read, P. R. Wiepkema, & P. E. Nachtigall (Eds.), *The biology of the harbour porpoise* (pp. 367–383). Woerden, The Netherlands: De Spil Publishers.
- Kastelein, R. A., de Haan, D., Vaughan, N., Staal, C., & Schooneman, N. M. (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.
- Kastelein, R. A., Hagedoorn, M., Au, W. W. L., & de Haan, D. (2003). Audiogram of a striped dolphin (*Stenella coeruleoalba*). *Journal of the Acoustical Society of America*, 113, 1130–1137.
- Kastelein, R. A., Janssen, M., Verboom, W. C., & de Haan, D. (2005). Receiving beam patterns in the horizontal plane of a harbor porpoise (*Phocoena phocoena*). *Journal of the Acoustical Society of America*, 118, 1172–1179.
- Kastelein, R. A., Rippe, H. T., Vaughan, N., Schooneman, N. M., Verboom, W. C., & de Haan, D. (2000). The effect of acoustic alarms on the behavior of harbor porpoises (*Phocoena phocoena*) in a floating pen. *Marine Mammal Science*, 16, 46–64.
- Kastelein, R. A., Verboom, W. C., Muijsers, M., Jennings, N. V., & van der Heul, S. (2005). The influence of acoustic emissions for underwater data transmission on the behaviour of harbour porpoises (*Phocoena phocoena*) in a floating pen. *Marine Environmental Research*, 59, 287–307.
- Koschinski, S., Culik, B. M., Damsgaard Hendriksen, O., Tregenza, N., Ellis, G., Jansen, C., et al. (2003). Behavioural reactions of free-ranging porpoises and seals to noise of a simulated 2 MW windpower generator. *Marine Ecology Progress Series*, 265, 263–273.
- Kraus, S., Read, A. J., Solow, A., Baldwin, K., Spradlin, T., Williamson, J., et al. (1997). Acoustic alarms reduce porpoise mortality. *Nature*, 388, 525.
- Laake, J., Rugh, D., & Baraff, L. (1998). *Observations of harbor porpoise in the vicinity of acoustic alarms on a set gill net*. NOAA Technical memorandum NMFS-AFSC-84. US Department of Commerce. 40pp.
- Lien, J., Hood, C., Pittman, D., Ruel, P., Borggaard, D., Chisholm, C., et al. (1995). Field tests of acoustic devices on groundfish gillnets: assessment of effectiveness in reducing harbour porpoise by-catch. In R. A. Kastelein, J. A. Thomas, & P. E. Nachtigall (Eds.), *Sensory systems of aquatic mammals* (pp. 349–364). Woerden, The Netherlands: De Spil Publishers.
- Lowry, N., & Teilmann, J. (1994). *Harbour porpoise (Phocoena phocoena) in Danish waters. Status, bycatch and possibilities for bycatch reduction. Report of the Danish Institute for Fisheries Technology and Aquaculture*. North Sea Centre, P.O. Box 59, DK-9850 Hirtshals, Denmark. 46pp.
- Monteiro-Neto, C., Avila, F. J., Jr., Alves, T. T., Araujo, D. S., Campos, A. A., Martins, A. M., et al. (2004). Behavioral responses of *Sotalia fluviatilis* (Cetacea, delphinidea) to acoustic pingers, Fortaleza, Brazil. *Marine Mammal Science*, 20, 145–151.
- Morton, A. B., & Symonds, H. K. (2002). Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. *ICES Journal of Marine Science*, 59, 71–80.
- Palka, D. L., Read, A. J., Westgate, A. J., & Johnston, D. W. (1996). *Summary of current knowledge of harbour porpoises in US and Canadian Atlantic waters*. Report of the International Whaling Commission, Vol. 46, pp. 559–565.
- Olesiuk, P. F., Nichol, L. M., Sowden, M. J., & Ford, J. K. B. (2002). Effect of sound generated by an acoustic harassment device on the relative abundance of harbor porpoises (*Phocoena phocoena*) in Retreat Passage, British Columbia. *Marine Mammal Science*, 18, 843–862.
- Polacheck, T., & Thorpe, L. (1990). *The swimming direction of harbor porpoises in relationship to a survey vessel*. Report of the International Whaling Commission, Vol. 40, pp. 463–470.
- Read, A. J., & Gaskin, D. E. (1988). Incidental catch of harbor porpoises by gill nets. *Journal of Wildlife Management*, 52, 517–523.
- Richardson, W. J., Greene, Ch. R., Malme, Ch. I., & Thomson, D. H. (1995). *Marine Mammals and Noise*. London: Academic Press, Inc.

- Ryan, B. F., & Joiner, B. L. (1994). *Minitab handbook* (third ed.). Belmont, CA: Duxbury Press.
- Trippel, E. A., Wang, J. Y., Strong, M. B., Carter, L. S., & Conway, J. D. (1996). Incidental mortality of harbour porpoise (*Phocoena phocoena*) by the gill-net fishery in the lower Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Sciences*, 53, 1294–3000.
- Trippel, E. A., Strong, M. B., Terhune, J. M., & Conway, J. D. (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.
- Zar, J. H. (1999). *Biostatistical analysis* (fourth ed.). NJ: Prentice Hall.