Will harbour porpoises (*Phocoena phocoena*) habituate to pingers?

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ABSTRACT

Large bycatches of harbour porpoises (*Phocoena phocoena*) occur in gillnet fisheries throughout the Northern Hemisphere. Several mitigation measures, including acoustic deterrent devices or ‘pingers’, have been used in efforts to reduce this bycatch. The potential exists for harbour porpoises to habituate to pingers, thus reducing their effectiveness over time. A field experiment was conducted to test the hypothesis that porpoises habituate to the sound produced by pingers. Porpoise echolocation and movements were monitored around a mooring equipped with a pinger (*Dukane NetMark*™ 1000) for three months in summer 1998 in the Bay of Fundy. Using a mean-shift model it was estimated that porpoises were initially displaced 208m from the pinger ($p = 0.019$), but this displacement diminished by 50% within four days ($p = 0.019$). Using a probability model it was demonstrated that the probability of porpoises within 125m of the pinger initially decreased when the pinger was turned on, but then increased to equal the control in 10-11 days. Echolocation rate ($p < 0.001$) and occurrence ($p < 0.001$) were significantly reduced in the vicinity of the pinger. These results indicate that porpoises habituated to the *Dukane NetMark*™ 1000 pinger and are not alerted to echolocate in the presence of nets by pingers.

KEYWORDS: BEHAVIOUR; ECHOLOCATION; FISHERIES; GILLNETS; INCIDENTAL CAPTURE; NOISE; BYCATCH

INTRODUCTION

Large numbers of dolphins and porpoises die in gillnets worldwide, posing serious threats to several populations and species (Jefferson and Curry, 1994; Perrin *et al*., 1994). Acoustic alarms or ‘pingers’ are currently used in several fisheries to reduce these bycatches (Kraus *et al*., 1997; Cameron, 1998; Trippel *et al*., 1999; Gearin *et al*., 2000). As the use of pingers spreads, concerns have been raised about their long-term effectiveness (Dawson *et al*., 1998). This issue of acoustic alarms has recently been reviewed by the Scientific Committee of the International Whaling Commission (IWC, 2000).

One of the most intensive efforts to reduce small cetacean bycatch has occurred in the Gulf of Maine. Between 1992 and 1996, an average of 2,100 harbour porpoises (*Phocoena phocoena*) died annually in Gulf of Maine sink gillnets - approximately 4% of the estimated population of 54,300, a rate that greatly exceeded allowable removal levels set under USA legislation (Waring *et al*., 1999). Kraus *et al*. (1997) demonstrated that pingers caused a significant reduction in the bycatch rate of harbour porpoises in the Gulf of Maine. Fishermen have taken an active role in the development and testing of pingers and are supportive of their widespread use in this fishery. Consequently, the use of pingers was recommended as an integral component of the management plan designed to reduce incidental mortality to sustainable levels (Federal Register, 1998).

In addition to recommending the use of pingers in the Gulf of Maine, the management plan recommended that research be conducted on several aspects of their use, including the potential for habituation. Habituation is defined as ‘the relatively permanent waning of a response as a result of repeated stimulation which is not followed by any kind of reinforcement’ (Thorpe, 1966). Participants at a workshop sponsored by the US National Marine Fisheries Service and the Marine Mammal Commission also noted the possibility that the effectiveness of pingers could decline due to habituation (Reeves *et al*., 1996). As more and more pingers are used in the Gulf of Maine, the avoidance response of harbour porpoises to these pingers could wane, reducing the efficacy of this management tool.

The purpose of this study was to evaluate the potential for porpoises to habituate to pingers. This experiment, conducted in the summer of 1998, forms part of a larger research programme designed to address the question of habituation. Another important aspect of this overall programme is to monitor the observed bycatch rate of porpoises over time in areas where pingers are used, to determine whether or not habituation is occurring. In the field experiment described here, a technique similar to that employed by Koschinski and Culik (1997) is used, in which shore-based observers used a theodolite, or surveyor’s transit, to track the movements of porpoises in the vicinity of active pingers. In a study of six days duration, Koschinski and Culik noted that porpoises avoided an experimental net equipped with pingers. Similar findings have been reported by Kastelein *et al*. (1997) for porpoises in a captive setting. In this study, patterns of harbour porpoises were monitored in relation to pingers over longer periods to assess the potential for habituation.

METHODS

Study area and experimental design

Porpoises were observed from a cliff on Grand Manan Island, New Brunswick, Canada between 26 June 1998 and 14 September 1998. This area has a high density of harbour porpoises during the summer months (Waring *et al*., 1999). A single *Dukane NetMark*™ 1000 pinger was attached 10m below the surface to a mooring at 44°47.7’N, 66°48.2’W (Fig. 1). The mooring was approximately 1,000m offshore and was set in 75m of water. The *Dukane NetMark*™ pinger emits a regular interval pulsed, broad-band signal with a fundamental frequency of 10kHz and a minimum sound pressure level of 132dB *re* 1μPa at 1m, which meets the

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current regulatory specification for a pinger in the Gulf of Maine (Federal Register, 1998). During an initial two-week training period, porpoises were tracked by the study team to improve proficiency in the use of the theodolite (see below). Porpoises were then tracked for two weeks around the mooring while the pinger was attached but not turned on - Control 1 (Table 1). On 11 July, the pinger was turned on and porpoises were tracked for four weeks - Experimental Trial 1. On 7 August, the pinger was turned off, and tracking began again on 19 August - Control 2. At this time a porpoise echolocation detector, POD, was also attached (see below). On 2 September the pinger was turned back on, and tracking continued for four weeks - Experimental Trial 2.

The sound pressure level and frequency of the *Dukane* pinger decrease with decay in battery voltage (Trippel *et al.*, 1999), so the pinger batteries were changed once a week and the voltage of each battery was tested after it was removed.

Table 1

Timing of habituation trials. Trial 2 was terminated early due to poor weather conditions.

	Begin	End	Pinger	POD
Training	6 Jun.	22 Jun.	Off	-
Trial 1				
Control	26 Jun.	10 Jul.	Off	-
Experimental	11 Jul.	7 Aug.	On	-
Trial 2				
Control	19 Aug.	2 Sep.	Off	On
Experimental	2 Sep.	14 Sep.	On	On

Tracking

Two researchers tracked porpoises using a *Geodolite* 404 total station and a *Husky* FS/GS data collector from a 100m cliff approximately 1,000m from the mooring. The observational area encompassed a 500m radius around the mooring. One researcher, the *surveyor*, used Fujinon 7 × 50 binoculars to scan the observational area for porpoises. The surveyor looked in concentric circles around the mooring, extending out to 500m. This individual reported sightings of porpoises to the *tracker*, the researcher stationed at the theodolite. The tracker used the theodolite to track surfacings of the lead porpoise in a group until: (1) the animals left the study area; or (2) the tracker lost sight of the porpoises or could not confirm that it was the same group. The tracker then began tracking the next group of porpoises identified by the surveyor. During the training period, the researchers tested their ability to estimate 500m from the mooring in all directions. The theodolite was used to measure the distances and ground-truth the estimates. After two weeks of training, both researchers were able to estimate 500m to within 10m in all directions.

Echolocation

On 20 August 1998 a POD was attached to the mooring. The POD continuously logged the number of echolocation clicks in 10s intervals. The POD was programmed to record several

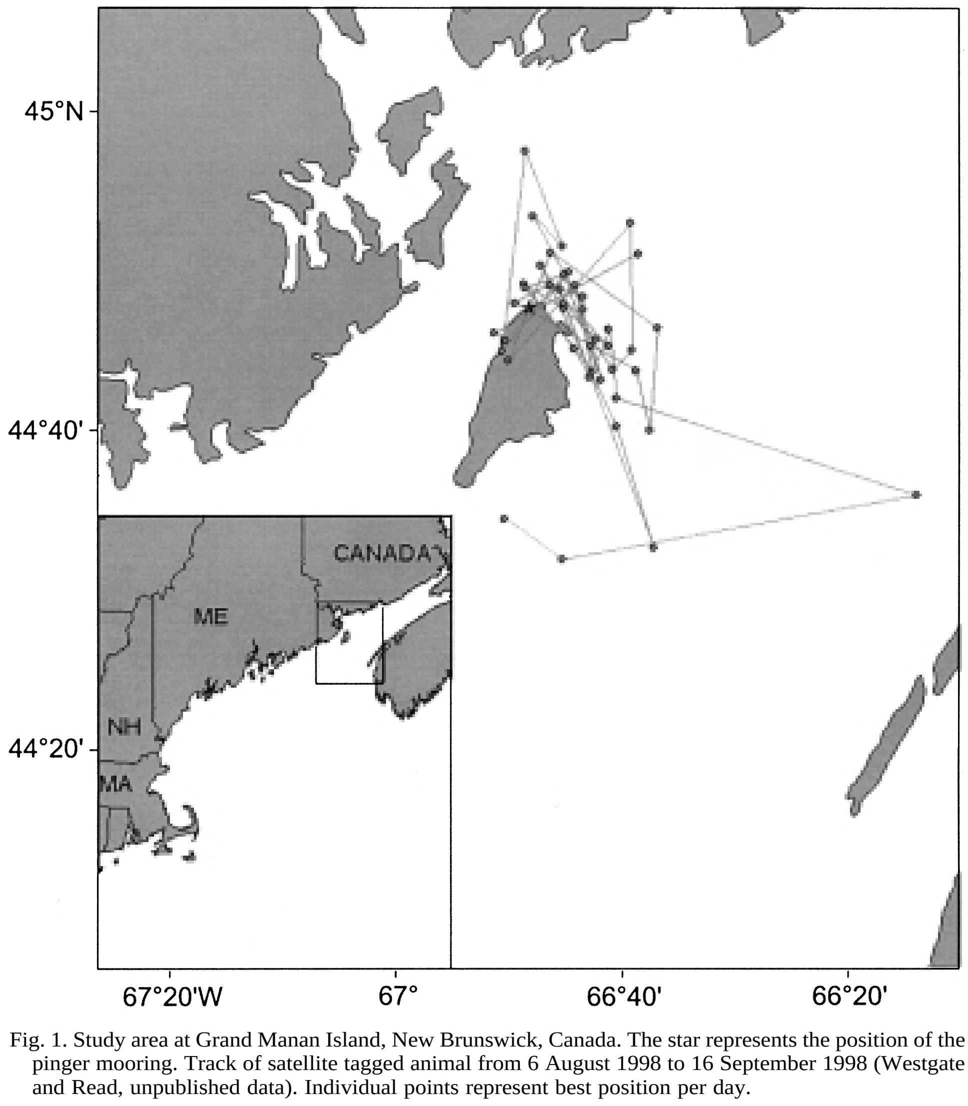

Fig. 1. Study area at Grand Manan Island, New Brunswick, Canada. The star represents the position of the pinger mooring. Track of satellite tagged animal from 6 August 1998 to 16 September 1998 (Westgate and Read, unpublished data). Individual points represent best position per day.

channels of echolocation clicks of varying duration and frequency. The frequencies were fixed at 50kHz, 93kHz and 132kHz. Porpoises produce distinctive narrow band sonar clicks from 110-150kHz (Mohl and Andersen, 1973; Kamminga and Wiersma, 1981) and so only clicks at 132kHz were used in the analysis. Single click durations for harbour porpoises are typically 100µs (Mohl and Andersen, 1973), so the POD was programmed to capture any click that lasted up to 400µs in duration.

Response variables

From the results of previous studies, a change in porpoise behaviour was expected when the pinger was first activated. Then, if habituation occurred, a gradual waning of this response was expected to occur over the experimental period. Three variables that have direct relevance to entanglement were examined: the *point of closest approach* to the pinger, *echolocation rate* and *echolocation occurrence*. The point of closest approach was defined as the minimum distance between the pinger and a surfacing porpoise. Echolocation rate was the number of clicks recorded per unit time and echolocation occurrence was the proportion of 10 second intervals in which clicks were detected.

Sound field

The sound field radiated by the pinger was measured on 26 September 1998. The day was overcast and the Beaufort Sea State was 2, diminishing to 1. Researchers drifted past the mooring in a small boat while the position of the boat was recorded from shore using the theodolite. The observers in the boat monitored the sound produced by the pinger with a *Bruel and Kjaer* 8100 calibrated hydrophone and a 2635 charged coupled pre-amplifier, which included a reference signal (160Hz, 174dB re1µPa@1m) generator. The weighted hydrophone was deployed 10m below the drifting boat. The calibration signal and hydrophone signal were recorded on a *Sony* TCD-D8 DAT recorder. Using *Syntrillium Software Corporation's* Cool Edit Pro version 1.1, the recordings were uploaded using 16-bit, single-track settings. A power spectrum (FFT 1,024 points; Blackman-Harris window) was then created to estimate the sound pressure level of the pinger in relation to the reference signal. By comparing the relative decibel level of the pinger to the known decibel level of the reference signal, the absolute decibel level of the pinger could be calculated.

Analysis

Two models were used to examine the data. First, a mean-shift model was used to test the hypothesis that porpoises were initially displaced from the pinger and then gradually moved closer to the pinger:

$$E(Y_j) = \beta_0 + \beta_1^{\,(-\beta_2\,(t_j - t_a))}\, I_{t_a}(t_j)$$

where:

$E(Y_j)$ is the expected distance of closest approach for group j ($j = 1, 2, 3, \ldots, n$)
β_0, β_1, and β_2 are unknown parameters:
β_0 is the control mean
β_1 is the mean shift due to the pinger
β_2 is the rate at which the pinger effect decays to 0
t_j is the day on which group j was observed
t_a is the day the pinger was turned on
$I_{ta}(t_j) = 1$ if $t_j > t_a$, otherwise $I_{ta}(t_j) = 0$.

Under this model, mean distance (β_0) is constant prior to activation. Following activation, there is an immediate increase (β_1) in the mean distance. This increase declines with time at rate β_2. The time after t_a at which the mean shift has been reduced by 50% can then be defined as:

$$T_{50} = -\log 0.5 / \beta_2$$

To test whether there was an initial response when the pinger was turned on, the null hypothesis H_0: $\beta_1 = 0$ was tested against the one-sided alternative hypothesis H_1: $\beta_1 > 0$. Using a randomisation test (Manly, 1991) samples were generated under H_0 by randomising the assignment of the observed values of Y_j to observation dates and fitting the null model by least squares. The significance level was estimated by the proportion of randomised datasets for which the residual sum of squares was less than that from fitting the model to the non-randomised data.

To test whether there was a significant waning of response over time, the null hypothesis H_0: $\beta_2 = 0$ was tested against the one-sided alternative H_1: $\beta_2 > 0$. In this case, only those values of Y_j for which $t_j \geq t_a$ were permuted.

Porpoises can probably not detect the pinger out to 500m (Kraus *et al*., 1997) and so a second model was used to test the probability that the proportion of sightings within 125m changed over time in response to the pinger. The distance of 125m was chosen based on sound field analysis (see below) and Laake *et al.*'s (1998) published displacement distance. The general model is:

$$Prob(X_j = 1) = \begin{cases} p_0 & 0 \leq t_j < t_a \\ p_1 & t_a \leq t_j < \theta \\ p_2 & t_j \geq \theta \end{cases}$$

where t_a is the known day of activation of the pinger and θ corresponds to the beginning of the habituation period. The binary random variable was chosen as $X_j = 1$ if the closest approach of group j is within 125m of the pinger and 0 otherwise, and t_j was chosen as the day on which this group was observed. Under this model the probability of a sighting within 125m prior to activation (p_0) is constant. Following activation this probability falls to p_1. However, beginning on day θ, this probability rises to p_2.

Each of the following null hypotheses was tested against the general model:

$$H_0^1: p_0 = p_1 = p_2$$
$$H_0^2: \theta = \infty$$
$$H_0^3: p_0 = p_2$$

Under H_0^1, there is no effect of the pinger on proportion of porpoises within 125m. Under H_0^2 there is an effect, but no habituation. Under H_0^3, there is full habituation. In each case the likelihood ratio statistic was used. In testing H_0^1 and H_0^2 against the general model, randomisation tests were used. The former case involved randomising the full set of observed distances; the latter case involved randomising only the post-activation distances.

A univariate factorial analysis of variance was used to examine variation in echolocation rate as a function of the state of the pinger (on or off) and time of day. Day was defined as occurring between 07:00 and 18:59 and night occurred between 19:00 and 06:59 (Westgate *et al*., 1995). A Chi-squared test was also used to compare the proportion of 10s intervals in which echolocation clicks occurred when the pinger was off and on. Means are presented with their associated standard deviations.

RESULTS

The closest observed approach of the porpoises to the active pinger decreased over time (Fig. 2). Poor weather forced truncation of the second trial. Thus the sample size was

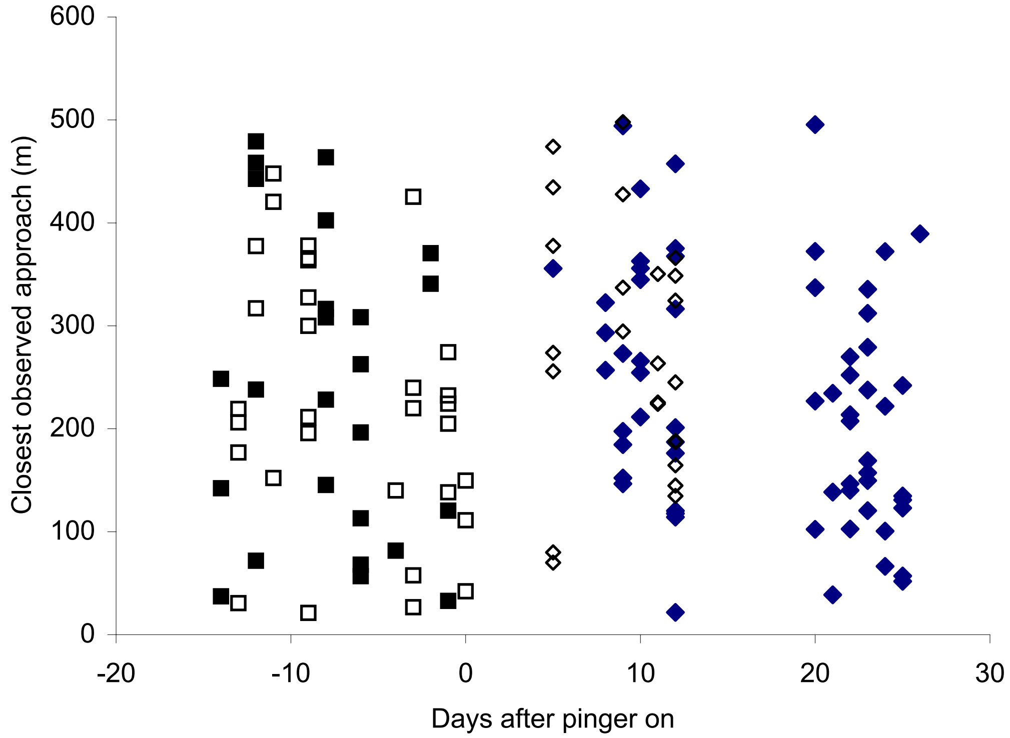

Fig. 2. Closest observed approach for Trials 1 and 2 pooled. (■) = Control, Trial 1; (◆) = Experimental, Trial 1; (□) = Control, Trial 2; (◊) = Experimental, Trial 2.

small, so both experiments were pooled to increase the power and test the mean-fit model. Results of the mean-shift model for both experimental trials and the pooled trials are presented in Table 2.

For the probability model all three null hypotheses were tested for Trial 1. Trial 2 was truncated, so only an effect of the pinger was tested. In Trial 1, the null hypotheses of no effect ($p = 0.02$) and no habituation ($p = 0.0$) were rejected; however, the null hypothesis of full habituation ($p = 0.39$) was not rejected. The maximum-likelihood estimates of the parameters under full habituation were:

$$\hat{p}_0 = \hat{p}_2 = 0.30 \qquad \hat{p}_1 = 0.00 \qquad \hat{\theta} = 10 - 11 \; days$$

It is not possible to distinguish between habituation times of 10 or 11 days because no observations were made on Day 11 following activation. For Trial 2, there was no significant difference between the p_0 (0.19) and p_1 (0.08) ($p = 0.12$).

A time of 30 minutes was chosen for the analysis of echolocation rate because only one group of porpoises remained in the area for more than this period (31 minutes). Therefore, independence among measurements of the number of echolocation clicks per half hour was assumed. Echolocation detection rate for the control (516±2,062; $n = 288$) was significantly greater than when the pinger was active (82±366; $n = 496$) ($p < 0.001$). In addition, echolocation detection rate was higher at night (377±1,699; $n = 432$) than in the day (75±409; $n = 352$) ($p < 0.001$) for both control and active periods. The proportion of 10 second intervals in which clicks were detected decreased after the pinger had been activated (control = 0.174; experimental = 0.041) ($\chi^2 = 9{,}241$; $p < 0.001$).

Received sound pressure levels of the 10kHz signal became indistinguishable from background noise at approximately 125m from the pinger (Fig. 3). Battery voltages averaged 5.85V ± 0.06V when removed from the pinger.

DISCUSSION

Habituation

The analysis suggests that porpoises habituated to the presence of the pinger. Both models indicated an initial response and then a waning of that response. When the two trials were pooled in the mean-shift model, porpoises were initially displaced from the pinger, but this displacement waned over time. Despite a small sample size and truncation of the second trial, similar patterns were observed in each of the two individual trials in the mean-shift model. In addition, the probability that porpoises approached within 125m of the pinger initially decreased, then increased after 10-11 days. Thus, porpoises habituated to the pinger and approached it more closely over time.

Demonstration of habituation typically relies on repeated observations of known individuals (Richardson *et al.*, 1995).

Table 2

Results of mean-shift model. Significance values are in parentheses after the test parameters.

	Control n	Experiment n	Control mean (β_o)	Mean shift (β_1)	Rate of decay (β_2)	Time to 50% decay (T_{50})
Trial 1	25	62	217m	519m (0.07)	0.25 (0.04)	2.8 days
Trial 2	31	24	225m	113m (0.07)	0.08 (0.27)	8.5 days
Pooled	56	86	220m	208m (0.02)	0.16 (0.02)	4.4 days

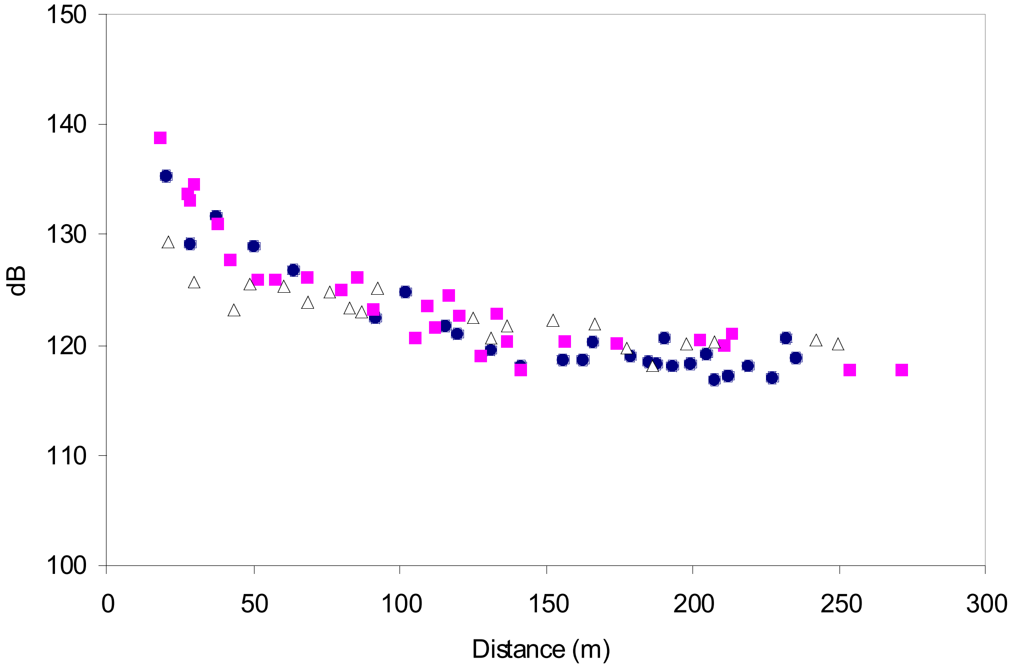

Fig. 3. Sound power spectrum level (dB re 1μPa) versus distance from the pinger. (●) = Drift 1; (□) = Drift 2; (Δ) = Drift 3. At approximately 125m, the 10kHz peak in the power spectrum became indistinguishable from background noise.

It was not possible to identify individual porpoises as their movements were tracked with the theodolite. However, previous studies of the movements of porpoises in the Grand Manan area using satellite and VHF telemetry have shown that individual animals are present in particular areas for weeks or months (Read and Westgate, 1997). For example, a porpoise tagged with a satellite-linked radio transmitter was tracked around the mooring on 1 September 1998. This porpoise had been in the area for several weeks (Fig. 1). Thus, individual porpoises likely experienced multiple exposures to the pinger over the course of the experiment.

The estimate using the mean-shift model of an initial displacement of 208m is larger than the 125m displacement used for the probability model. In addition, the time to response decay in the mean-shift model is considerably faster than the estimate of 10-11 days using the probability model. However, the precision of estimates of initial displacement and rate of decay in the mean-shift model is relatively low, since few observations were made immediately after the pinger had been activated. The results show a relatively large initial displacement, followed by a relatively rapid habituation. However, no observations were made immediately following activation of the pinger, so the possibility of a smaller initial displacement and a longer period of habituation can not be ruled out. Nevertheless, this imprecision does not affect the conclusions that porpoises were initially displaced by the pinger and then approached it more closely over time.

The experimental protocol involved only a single pinger on a mooring, so it is not possible to say with certainty that porpoises will habituate to pingers attached to a gillnet. In fact, even if habituation occurs, it may not lead to an increase in bycatch rate if there is enough residual effect to keep porpoises away from nets. Another plausible scenario is one in which as porpoises habituate and approach the pinger more closely, the sound may stimulate them to investigate their surroundings more thoroughly and thus avoid the net. This scenario assumes that the porpoise will perceive the net as a barrier or danger. Ultimately, a monitoring programme is necessary to ensure bycatches do not increase as porpoises habituate to pingers used in a commercial setting (IWC, 2000).

The decrease in battery voltage would not have resulted in a significant decay in frequency or amplitude of the pinger (Trippel *et al*., 1999). However, it is unlikely that fishermen will replace batteries every week. Thus, battery decay and resultant changes in pinger function could lead to a decay in their effectiveness in a commercial fishery. Pingers are currently being developed that regulate the voltage supply so that frequency and sound pressure do not decay with falling battery voltage (A.D. Goodson, pers. comm.).

The experimental protocol also only involved a single type of pinger - the *Dukane NetMark*™ 1000. Other types of pingers with different sound characteristics, including frequency sweeps as opposed to tonal pulses, varied inter-pulse intervals and randomised frequency over time, are currently being developed (A.D. Goodson, pers. comm.). As these pingers become commercially available, they should be thoroughly tested to determine if they will reduce the likelihood of habituation.

Echolocation

Elucidating the mechanism by which pingers work will further aid in determining if porpoises will habituate to pingers on gillnets (see below). For example, if the sound of pingers is aversive to porpoises, they are likely to habituate to it. However, if pingers alert porpoises to the presence of a barrier which they perceive as dangerous, they may be less likely to habituate.

Kraus *et al*. (1997) hypothesised that pingers might stimulate porpoises to echolocate and thus detect a gillnet. This hypothesis was tested here by examining echolocation rates of porpoises in relation to the moored pinger. The reduction in echolocation rate (number of clicks per unit time) when the pinger was activated demonstrated that porpoises were either echolocating less frequently in the vicinity of the pinger, using shorter click trains, or directing their sonar away from the pinger. If porpoises emitted a similar number of shorter trains, the proportion of 10s intervals containing clicks would be expected to be similar in control and experimental treatments. However, the proportion of 10s intervals in which echolocation events occurred was significantly reduced when the pinger was activated, suggesting that porpoises echolocate less frequently in the vicinity of an active pinger.

It is possible, and perhaps likely, that many porpoises were displaced from the pinger and the POD did not detect their echolocation signals. Preliminary studies estimate the range of the POD to be 50-100m (T. Cox, unpublished data). This distance is considerably greater than the distance (2-9m) at which porpoises can detect nets with floatlines using echolocation (Hatakeyama and Soeda, 1990). None of these explanations supports the hypothesis of Kraus *et al*. (1997) that the *Dukane NetMark*™ 1000 pinger stimulates porpoises to echolocate, as the echolocation frequency of porpoises around the pinger did not increase when the device was activated.

Even during the control period, echolocation clicks were recorded only 17% of the time. Porpoises were tracked around the mooring at this time, and three times porpoises were oriented towards the mooring within 50m of the pinger, but no echolocation clicks were recorded. Thus, it is likely that porpoises are not echolocating constantly. This finding has relevance for the development of other acoustic means of reducing bycatch, particularly those which rely on a passive approach.

Because Trial 2 was truncated due to poor weather conditions, changes in echolocation response to the pinger over time were not monitored. Future studies should monitor echolocation rate and frequency as additional response variables that could wane over time. Investigating these responses over time would further elucidate the potential for porpoises to habituate to the presence of a pinger.

CONCLUSION

The results suggest that the effects of habituation need to be considered when pingers are used to reduce the bycatch of small cetaceans. Long-term monitoring of bycatch using observers is necessary to ensure the effectiveness of pingers in gillnet fisheries (IWC, 2000). This study was not designed to test hypotheses of the mechanism by which pingers reduce harbour porpoise bycatch, but was able to reject the hypothesis that pingers stimulate harbour porpoises to echolocate and thus detect a gillnet. Monitoring harbour porpoise echolocation around gillnets equipped with pingers could further elucidate the mechanism by which pingers reduce bycatch.

ACKNOWLEDGEMENTS

This research was conducted at the Grand Manan Whale and Seabird Research Station. Special thanks go to Jeremy Rusin, Andrew Westgate, Dave Johnston, Heather Koopman, Krystal Tolley, Rob Ronconi and Sarah Wong for assistance in the field. Additional assistance was provided by the fishermen of Grand Manan, especially Jeff Foster and Steven Bass. Equipment and aid for mapping the sound field were provided by Dr Jack Terhune and Dave Johnston. The experimental design was improved by comments from Jay Barlow and the US Marine Mammal Commission and its Committee of Scientific Advisors. We thank Dave Johnston, Finn Larsen and Dave Goodson for their thoughtful reviews of this manuscript. This project was funded by the US National Marine Fisheries Service, Northeast Fisheries Science Center under Co-operative Agreement NA77FL0373.

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