

Is attempting to change marine mammal behaviour a generic solution to the bycatch problem? A dugong case study

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Abstract

Incidental bycatch in fishing nets is a global cause of incidental mortality of marine mammals. Two classes of approaches attempt to mitigate this impact: (1) approaches that change the behaviour of the fisher (e.g. closures and gear modifications), (2) approaches that attempt to change the behaviour of the bycatch species (e.g. acoustic alarms or pingers). Even though the effectiveness of pingers has been established for very few bycatch species, pingers are now mandatory in many fisheries throughout the world. Pingers are being trialled in commercial gill net fisheries in tropical Australia to reduce the bycatch of the dugong and three species of coastal dolphins, despite an absence of robust assessments of: (1) their effectiveness in reducing bycatch, (2) the likelihood of alienating bycatch species from critical habitats. We conducted replicate experiments to test the behavioural responses of dugongs to 4 and 10 kHz pingers in an array simulating a net. Each experiment comprised three sequential 10-min treatments in which two pingers were: (1) inactive, (2) active, (3) inactive. The rate of decline of the number of dugongs within the focal arena did not change significantly while pingers were activated. Dugongs passed between the pingers (where a net would be located) irrespective of whether the alarms were active or inactive, fed throughout the experiments and did not change their orientation to investigate pinger noise, or their likelihood of vocalizing. We conclude that: (1) pingers are unlikely to alienate dugongs from critical habitats or reduce dugong mortalities in fishing nets, (2) bycatch mitigation strategies such as pingers that rely on changing animal behaviour should only be used after rigorous testing on all likely bycatch species.

Introduction

The incidental catch of marine mammals in fishing gears, especially gill nets, is one of the greatest immediate threats to marine mammals throughout the world; the death toll from fishing nets far exceeds the deliberate catch (Reeves *et al.*, 1996, 2005). Solutions to the marine mammal bycatch problem aim to change either: (1) the fishers' behaviour (e.g. changes to fishing practices, temporal or spatial closures), (2) the animals' behaviour. The latter category includes pingers (acoustic alarms) designed to reduce bycatch by either: (1) producing aversive sounds that keep marine mammals away from nets, or (2) alerting animals to investigate their surroundings (Dawson, 1994; Dawson, Read & Slooten, 1998; Kraus, 1999).

Pingers have been considered a promising solution to the bycatch problem for several cetaceans including humpback whales *Megaptera novaeangliae* (Lien *et al.*, 1992), harbour porpoises *Phocoena phocoena* (Kraus *et al.*, 1997; Laake, Rugh & Baraff, 1998; Trippel *et al.*, 1999; Gearin *et al.*, 2000; IWC, 2000; Culik *et al.*, 2001), short-beaked common dolphins *Delphinus delphis* (Barlow & Cameron, 2003),

Franciscana dolphins *Pontoporia blainvillei* (Bordino *et al.*, 2002; Bordino & Kraus, 2004) and Hector's dolphins *Cephalorhynchus hectori* (Stone *et al.*, 1997).

Some fisheries managers now consider pingers to be a relatively uncontroversial and inexpensive generic bycatch mitigation measure. The use of pingers is mandatory in the Gulf of Maine and Mid-Atlantic waters (Federal Register, 1998), in the Californian/Oregon swordfish drift gillnet fishery (Federal Register, 1999) and for large fixed gear fishing vessels of European Union member states in the North Seas, Celtic Sea Channel and Western Waters (Council of the European Union, 2004).

Unfortunately, there may not be a universal solution to the capture of marine mammals in gill nets (IWC, 1994). Pingers are unlikely to reduce the bycatch of all species of marine mammals or even all cetaceans. Bottlenose dolphins *Tursiops truncatus* are not deterred from nets by pingers (Cox *et al.*, 2003). In contrast to harbour porpoises, which tend not to tolerate a new sound in their environment, bottlenose dolphins tend to investigate novel stimuli and may even approach pingers aggressively (Cox *et al.*, 2003; McPherson *et al.*, 2004).

This inter-specific variation among cetaceans suggests that responses will vary across other marine mammal taxa. Thus, despite the effectiveness of pingers for some species, it is important to consider the habits, hearing abilities and responses of each species of concern to sound and novel stimuli before mandating the use of pingers in a fishery (Dawson *et al.*, 1998; IWC, 2000; Kastelein *et al.*, 2000).

In Queensland, Australia, pingers have been developed and trialled for mitigating a multi-species bycatch problem that targets several cetaceans species and the dugong *Dugong dugon* (Marsh, 2000; Marsh *et al.*, 2005). A programme to test pinger use on both commercial gill nets and shark nets set for bather protection has been running since 1991 (Lien *et al.*, 1998; McPherson *et al.*, 2001, 2004). However, as McPherson *et al.* (2004) point out, bycatch rates in nets in Queensland are too low to test pinger effectiveness statistically on nets. The probability of a net catching dugongs is <1% per day (Marsh *et al.*, 2005). At least 2700 sets each of control and pinger-equipped nets would be required to demonstrate a 50% reduction in catch rates with 80% power (at $\alpha = 0.10$) (Dawson *et al.*, 1998). Such direct experiments are expensive. It cost US\$500 000 to test the effectiveness of pingers for harbour porpoises in New England in 1994 (Dawson *et al.*, 1998). A different approach is clearly required.

The alternative is to observe the behaviour of animals around arrays that simulate pingers on a fishing net (Reeves *et al.*, 1996; Stone *et al.*, 1997; Cox *et al.*, 2001; Culik *et al.*, 2001). Simulated experiments conducted in highly used habitat areas maximize observations of the animals' responses to pingers without risk of entanglement.

We used simulated experiments to observe the behavioural and acoustic responses of large groups of dugongs to pingers in clear water in Moreton Bay, Queensland, with the primary objective of ascertaining whether pingers were likely to alienate dugongs from their critical inshore habitats. Dugongs are highly susceptible to entanglement in nets (Heinsohn, Marsh & Spain, 1976), one of the greatest sources of human-caused mortality of dugongs throughout their global range (Marsh *et al.*, 2002). Our results provide the first quantitative insights into the likely effectiveness of pingers in reducing dugong bycatch.

Methods

Study site

We conducted 10 experiments using 10 kHz pingers during 6–11 August 2002, and 16 experiments using 4 kHz pingers during 8–31 July 2005, in Moreton Bay (153.3°E, 27.5°S), Queensland, Australia. Large herds of dugongs (typically about 150 animals) regularly use the Moreton Banks (Preen, 1992) where the research was conducted. Water depths are 1.3–4.8 m in the area, which has a sparse cover of *Halophila* and *Zostera* on clean, moving quartz sand and relatively clear water with 1–5 m horizontal visibility (Preen, 1992).

Observation platform

The dugongs were observed using a blimp-cam: a tethered, helium-filled aerostat (balloon) carrying a remote-control surveillance camera (detailed in Hodgson, 2004) flown at *c.* 50 m. The video camera was operated via a controller and monitor on the research vessel. Data were extracted from the video footage in the laboratory.

Pinger type and sound propagation

Four BASA pingers of the same nominal frequency (4 or 10 kHz) were used in each experiment. These are the two most common frequencies used to target whales (e.g. Lien *et al.*, 1992) and dolphins (e.g. Kraus *et al.*, 1997), respectively, and the two pinger types being used in Queensland during the time of the experiments. The source level (SL) for the 10 kHz pinger, according to the sound pressure level at 1 m is 133.2 dB re 1 μ Pa, and the SL of the 4 kHz pingers is 133.6 dB re 1 μ Pa (Baldwin, 2002). Both pinger types emit pulse sounds at 4-s intervals. Empirical investigations on the Moreton Banks showed that both pinger types are audible [≥ 20 dB above ambient noise (Richardson *et al.*, 1995)] to at least 100 m (Baldwin, 2002), encompassing our focal arena.

Pinger array

We conducted separate experiments using pingers of each nominal frequency. Either two active or two silent pingers were deployed simultaneously. At one end of the array, one silent and one active pinger were mounted above an anchored floating tube, and were alternately deployed using a remote joystick controller (Stone *et al.*, 1997). At the other end, either the active or silent pinger was hung from the bow of the research vessel (Fig. 1).

Pingers were lowered to a depth of 1 m, which was approximately mid-water in most experiments. The anchored tube was deployed by slowly motoring the research vessel to one edge of the dugong herd, switching off the motor, placing the anchored tube into the water, drifting the research vessel towards the opposite edge of the herd and anchoring 50–55 m from the tube. Experiments commenced at least 10 min after anchoring as the average rate of recovery of a dugong herd after boat disturbance is 2 min (Hodgson & Marsh, 2007).

Focal arena

The focal arena was limited by the field of view of the blimp-cam. As the two pairs of pingers were usually close to the near and far boundaries of the field of view, our focal arena was delimited by these two points (Fig. 1). Variations in the width of the focal arena (i.e. field of view) between experiments (37–53 m at the bottom and 59–105 m at the top) occurred with changing blimp position and camera angle, and were calibrated for each experiment assuming an average dugong length of 2.5 m (Fig. 1).

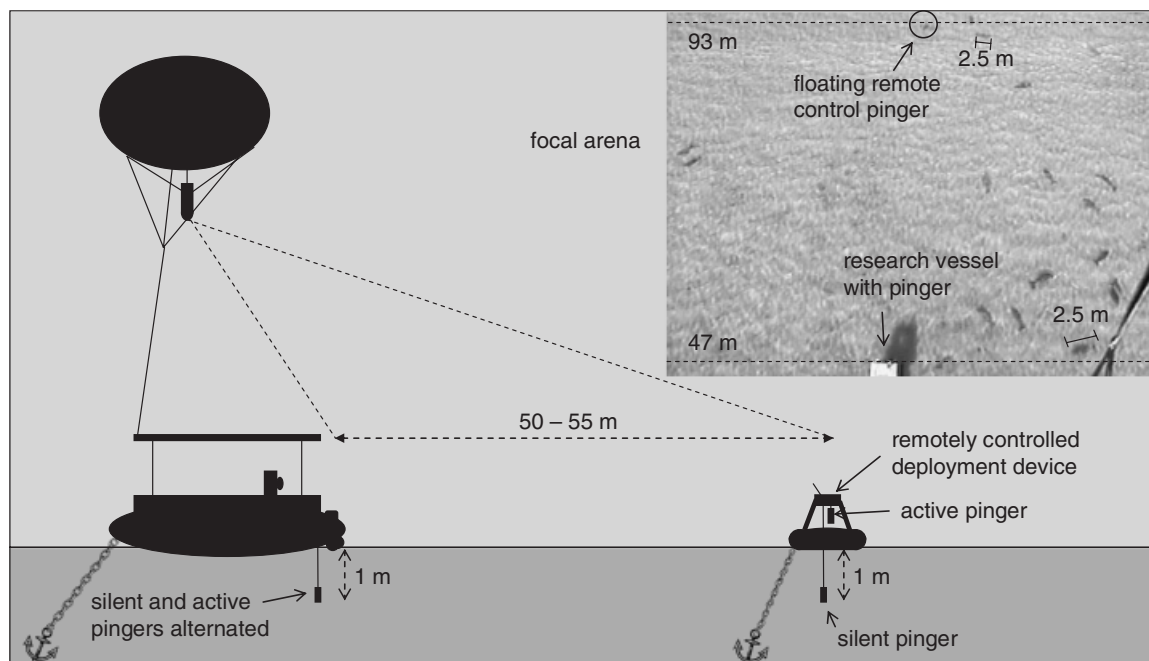


Figure 1 The array of two pingers: one deployed from the research vessel, one from a floating tube anchored at a set distance from the vessel. During the experiment, a silent pinger was exchanged (manually or using a remote control) with an active pinger at each deployment site. The focal arena viewed from the blimp-cam was bounded by the floating tube and the vessel. The width of view at the top and bottom of the arena was estimated using dugong *Dugong dugon* lengths as a reference when dugongs were aligned with these boundaries. The inset shows the dugongs in the focal arena as seen from the video footage taken by the blimp-cam.

Experimental protocol

Each experiment was divided into three 10-min sequential treatments: (1) pre-pinger – two silent pingers deployed, (2) pinger – two active pingers, (3) post-pinger – two silent pingers. The camera was positioned on the focal arena during odd minutes and panned to film the feeding behaviour of dugongs visible from the blimp-cam outside of the focal arena during even minutes.

Sound recordings

Sounds were recorded via an omnidirectional Hi Tech Inc (Hi Tech Inc., Gulfport, MI, USA) hydrophone (HTI-96-MIN, frequency response 2 Hz to 30 kHz, sensitivity -164 dB re 1 V μ Pa $^{-1}$), deployed next to the pinger at the bow of the research vessel at approximately mid-water and connected to a digital audio tape recorder (Sony, Sydney, Australia, TCD-D100, frequency response 20 Hz to 22 kHz). The tape recorder time stamped all recordings and was synchronized with the video recorder to enable visual and audio observations to be correlated. The hydrophone confirmed the functioning of the remote pinger.

Number of dugongs within the focal arena

We counted the number of individual dugongs within the focal arena from still images captured from the video footage at 1 min intervals, providing a series of instanta-

neous scan samples (Altmann, 1974). The counts were analysed to estimate differences in the mean count of dugongs in each treatment and differences in the rate of changes in dugong numbers over each treatment period. The data were characterized by repeated measures over time for each experiment, with experiments forming a random blocking structure for the analysis. A Poisson error distribution was assumed as the data were counts including some zeros. Exploratory analysis found no evidence for correlation structure among the observations within each experiment over time. The data were analysed using a generalized linear mixed-model with a log link, with the model represented as

$$\text{Dugong count} \sim (\text{treatment}^f \times \text{time}^f) + (\text{experiment}^f + (\text{experiment} \times \text{time})^f) + \varepsilon$$

where treatment was a fixed categorical effect representing the three periods of sampling defined by the presence of the pinger (pre-pinger, pinger, post-pinger), time was a fixed continuous effect representing the linear trend over the 10 sampling times within each treatment period and was centred (coded as -4.5 to 4.5) so that the treatment effect represented the mean count of dugongs in each period, and ε was the error term. Experiment and $\text{experiment} \times \text{time}$ represent additional random sources of variation ‘among experiments’ in the mean count and the slope of the linear trend, respectively. The estimates of random variance are

not presented here as the fixed effects of time and treatment were the relevant factors.

Orientation of dugongs within the focal arena

The orientation of each dugong relative to the pinger array at each 1-min scan was calculated using the 'Optimas 6.5' imaging program. A dugong was considered to be facing the array if it was facing within 180° of the imaginary line between the two in-water pingers. Only experiments where dugongs were present in the focal arena during at least two scans in all three treatments were analysed.

Passing between pingers

We used the one-zero method (Altmann, 1974) to record whether dugongs passed between the two pingers during each of the fifteen 1-min focal arena scans of each experiment. Only experiments where dugongs were within the focal arena during at least part of each treatment were analysed.

Feeding plumes

Active feeding by dugongs creates plumes of sediment that rise from behind the animals as they are extracting the rhizomes of the seagrass. We also used the one-zero method to record whether plumes from dugongs continuing to feed were visible within 100 m of either pinger when panning the entire area visible from the blimp-cam every second minute within each experiment.

Vocalizations and feeding sounds

Dugong vocalizations and feeding sounds were recorded during the 4 kHz pinger experiments. Spectrum analysis was conducted using 'Cool Edit 2000' software (Syntrillion Software Corporation, Phoenix, USA). Sounds were attributed to dugongs vocalizing based on descriptions by Anderson & Barclay (1995) and recordings of dugongs in Moreton Bay (A. J. Hodgson, unpubl. data). The distinctive repetitive grinding/chomping noise of feeding was identified audibly based on recordings associated with visual observations of wild (A. J. Hodgson, unpubl. data) and captive (H. Marsh, unpubl. data) dugongs. The one-zero method was used to record whether or not vocalizations or feeding sounds could be heard within each minute of the experiments.

Analysis

The differences in: (1) the proportion of individual dugongs oriented towards the pingers, (2) the probability of individuals passing between the pingers, (3) the probability of feeding plumes being observed within 100 m of the pinger array, (4) the probability of hearing dugong vocalizations, (5) the probability of hearing dugong feeding sounds, among treatment periods were analysed using generalized linear mixed-models with a logit link and binomial variance

function. Separate models were fitted for the experiments testing the two pinger types. Variability between experimental runs was modelled as a random effect. The relationship between the likelihood of: (1) individuals being oriented towards the pingers, (2) individuals passing between the pingers, (3) hearing either vocalizations or feeding sounds, and the number of dugongs within the focal arena was also assessed by including the logarithm (base = 2) of the number of dugongs within the focal arena as a covariate in the analysis. Likelihood ratio tests were used to assess the significance of model terms.

Not all dugongs within the audible range of the hydrophone were in the focal arena. Thus, we interpret the relationship between the likelihood of dugong vocalizing or producing feeding sounds, and the number of dugongs visible with caution.

Results

Number of dugongs within the focal arena

The mean number of individual dugongs present in the focal arena differed significantly among treatment periods for both 4 and 10 kHz pingers (Fig. 2, Table 1). The rate of change in the number of individual dugongs over time

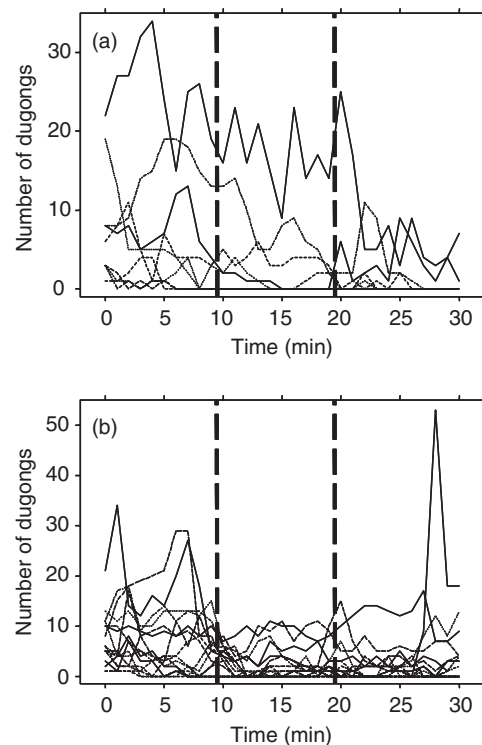


Figure 2 Number of dugongs *Dugong dugon* observed over time in each of the pre-pinger, pinger and post-pinger treatment periods while testing (a) the 10 kHz pingers and (b) the 4 kHz pingers. Line types represent replicate experiments, and thick dashed lines separate treatment periods.

Table 1 Results of the experiments to test the responses of dugongs *Dugong dugon* to 4 and 10 kHz pingers

Variable	Pinger type (kHz)	Result (95% confidence interval)			Statistics
		Pre-pinger	Pinger	Post-pinger	
Mean number of individual dugongs present in the focal arena	10	2.7 (1, 7.3)	1.3 (0.5, 3.6)	0.6 (0.2, 1.6)	F_{2,265} = 85.8, P < 0.01 F_{2,474} = 44.1, P < 0.01
	4	4.9 (3.1, 7.7)	1.8 (1.1, 3.0)	2.1 (1.3, 3.4)	
Rate of change in dugong numbers over time	10	Decreased at 11.9% (4, 20) min ⁻¹	Decreased at 14.4% (5.5, 24.1) min ⁻¹	Decreased at 25.6% (14.5, 37.8) min ⁻¹	F_{2,265} = 4.3, P = 0.014 Significant difference in rate of decline between pre-pinger and post-pinger only
	4	Decreased at 4.7% (0.5, 9.5) min ⁻¹	Decreased at 2.5% (-5.3, 10.5) min ⁻¹	Increased at 9.9% (2.2, 18.1) min ⁻¹	
Proportions of dugongs oriented towards the pinger array	10	0.69 (0.07, 0.99)	0.65 (0.11, 0.97)	0.67 (0.13, 0.97)	F_{2,474} = 6.5, P < 0.01 Rate of change significantly higher during post-pinger treatment due to one experiment – when removed, treatment effect not significant (# dugongs decreased at 1.5% (-5.0, 8.2) min ⁻¹ ; # dugongs = 1.8 (1.1, 2.9)) $\chi^2 = 0.04$, d.f. = 2, P = 0.98 Did not covary with # dugongs in focal arena: $\chi^2 = 0.01$, d.f. = 1, P = 0.91 $\chi^2 = 3.8$, d.f. = 2, P = 0.15 Did not covary with # dugongs in focal arena: $\chi^2 = 0.13$, d.f. = 1, P = 0.72
	4	0.77 (0.34, 0.95)	0.49 (0.20, 0.78)	0.53 (0.22, 0.82)	
Probability of dugongs passing between pingers	10	0.51 (0.15, 0.86)	0.46 (0.12, 0.84)	0.25 (0.05, 0.69)	$\chi^2 = 3.1$, d.f. = 2, P = 0.22 Probability increased with # dugongs in focal arena: $\chi^2 = 18.7$, d.f. = 1, P < 0.0001 $\chi^2 = 23.8$, d.f. = 2, P < 0.0001 Probability highest in the pre-pinger period and significantly lower during pinger and post-pinger periods, but effect of # dugongs significant: $\chi^2 = 89.1$, d.f. = 1, P < 0.0001 .
	4	0.65 (0.49, 0.78)	0.35 (0.21, 0.52)	0.26 (0.14, 0.43)	
Probability of dugong feeding plumes occurring within 100 m of the pinger array	10	0.73 (0.31, 0.94)	0.64 (0.23, 0.92)	0.78 (0.34, 0.96)	After controlling for # dugongs, treatment effect not significant: $\chi^2 = 0.9$, d.f. = 2, P = 0.65 $\chi^2 = 1.0$, d.f. = 2, P = 0.61 $\chi^2 = 1.5$, d.f. = 2, P = 0.49
	4	0.92 (0.62, 0.99)	0.88 (0.53, 0.98)	0.84 (0.45, 0.97)	
Probability of dugongs vocalizing	4	0.07 (0.03, 0.16)	0.11 (0.05, 0.23)	0.08 (0.03, 0.17)	$\chi^2 = 2.0$, d.f. = 2, P = 0.37; likelihood also not affected by # dugongs in focal arena $\chi^2 = 0.03$, d.f. = 1, P = 0.86
	4	0.08 (0.01, 0.36)	0.05 (0.01, 0.25)	0.08 (0.01, 0.35)	
Probability of hearing dugongs feeding	4				$\chi^2 = 2.2$, d.f. = 2, P = 0.34; likelihood increased as # dugongs visible in the focal arena increased $\chi^2 = 33.8$, d.f. = 1, P < 0.0001

Each experiment comprised three sequential 10-min treatments: (1) pre-pinger – two pingers inactive, (2) pinger – active, (3) post-pinger – inactive. Significant results in bold.

within treatment periods differed significantly among treatment periods for both pinger types; however, there was no significant difference in the rate of decrease in the number of dugongs between the pre-pinger and pinger periods. The rate of decrease was significantly greater in the post-pinger period than in the pre-pinger period for the 10 kHz pingers. In contrast, the number of dugongs increased significantly during the post-pinger period for the 4 kHz pingers. The last result was strongly affected by a sharp increase in the number of dugongs late in the post-pinger period during one experiment. When this experiment was removed from the analysis, there was no significant change in dugong numbers over the post-pinger period for the 4 kHz pingers (Table 1).

Orientation of dugongs within the focal arena

Six experiments using the 10 kHz pingers and 11 experiments using the 4 kHz pingers fitted our requirements for testing orientation. The proportions of dugongs oriented towards both the 4 and 10 kHz pingers in each experiment were not significantly different between the pre-pinger, pinger and post-pinger treatments and did not covary with the number of dugongs in the focal arena (Table 1).

Passing between pingers

Dugongs were observed passing between the two pingers of both pinger types when both silent and active pingers were deployed. There was no significant difference in the likelihood of dugongs passing between the two 10 kHz pingers between treatment periods (Table 1). In contrast, for the 4 kHz pingers, the probability was the highest in the pre-pinger period and significantly lower in the pinger and post-pinger period but this difference disappeared when the number of dugongs in the focal arena was accounted for in the analysis (Fig. 3, Table 1). For both pinger types, the likelihood of dugongs passing between the pingers was higher when more dugongs were present. A doubling of the number of dugongs in the focal arena increased the odds of individuals passing between pingers by a factor of 2.5 (95% CI = 1.6, 4.2) for the 10 kHz pingers and a factor of 3.2 (2.4, 4.3) for the 4 kHz pingers.

Feeding plumes

The likelihood of dugong feeding plumes occurring within 100 m of the pinger array was unaffected by the treatment effects of pinger noise for both pinger types (Table 1).

Vocalizations and feeding sounds

Multiple bouts of dugong vocalizations were recorded within nine experiments using 4 kHz pingers. The probability of dugongs vocalizing was not significantly affected by pinger noise or the number of dugongs visible in the focal arena. Dugong feeding sounds were heard during eight experiments. The probability of hearing dugongs feeding was not

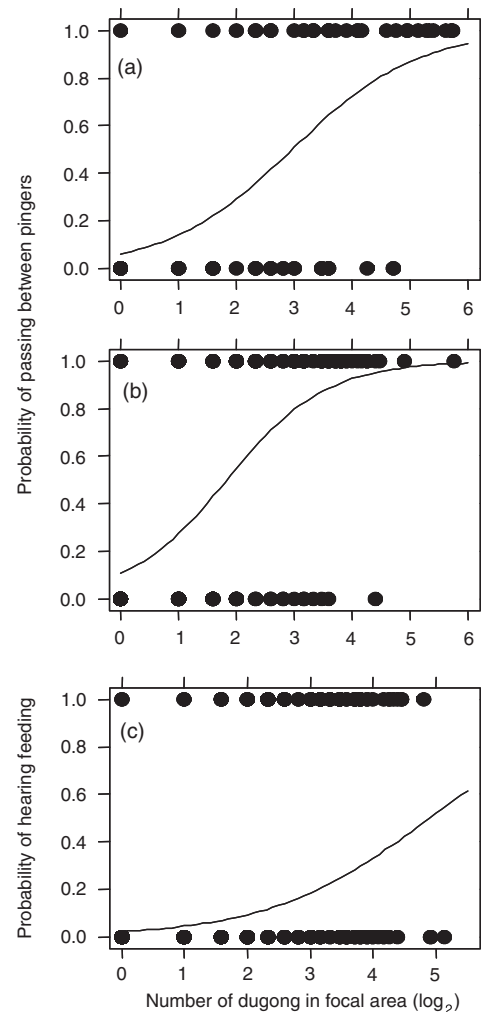


Figure 3 Likelihood of dugongs *Dugong dugon* passing between: (a) the 10 kHz and (b) the 4 kHz pingers in relation to the number of dugongs visible and (c) the probability of hearing dugong feeding sounds throughout 4 kHz pinger experiments in relation to the number of dugongs visible in the focal arena (\log_2 scale). The solid line represents the relationship estimated by a generalized linear mixed-model with a logit link function transformed to the probability scale; solid points represent the observed data.

significantly affected by pinger noise; however, the likelihood of hearing feedings sounds increased as the number of dugongs in the focal arena increased (Fig. 3, Table 1).

Discussion

We discuss our results in the context of the three main concerns about the *ad hoc* use of pingers in fisheries:

- (1) The potential for noise disturbance or displacement.
- (2) The effectiveness of pingers and the perception that pingers have addressed the bycatch problem.
- (3) The problems with relying on animals to change their behaviour to reduce multi-species bycatch.

Potential for noise disturbance or displacement

As a noise source, pingers may disturb or displace animals over large distances, effectively reducing the habitat available to a species and potentially causing damaging effects on a population equal to incidental deaths in fishing nets (Culik *et al.*, 2001). We showed experimentally that neither 10 nor 4 kHz pingers elicit a response from the dugongs in our study area. The decline in the number of dugongs in the focal arena throughout the experiments could not be attributed to pinger noise as the rate of decline did not increase significantly once active pingers were deployed. This suggests that the decline resulted from normal dugong movement patterns rather than the active pingers. Such a conclusion is supported by previous behavioural research demonstrating that undisturbed dugongs naturally move across a field of view over time as they forage, or in response to tidal movements or social interactions. In a previous study using the blimp-cam from an anchored boat, individual dugongs of ten went out of view (≥ 200 m from the boat) before the end of prescribed 15 min behavioural observations (Hodgson, 2004).

Our results indicate that dugongs would not be alienated from their feeding grounds by the two types of pingers tested. Dugongs continued feeding within 100 m (i.e. within the predicted zone of audibility) of the active pingers. Dugong feeding sounds were also audible throughout the pinger experiments, and the likelihood of hearing these sounds was positively correlated with dugong numbers, regardless of whether active or inactive pingers were deployed. There was no significant movement away from the active pingers and dugongs swam between active pingers set ≤ 55 m apart. Thus, concerns about pingers displacing dugongs are unfounded in contrast to some cetaceans including the tucuxi *Sotalia fluviatilis* (Monteiro-Neto *et al.*, 2004), harbour porpoise (Laake *et al.*, 1998; Culik *et al.*, 2001; Carlstrom *et al.*, 2002) and Hector's dolphin (Stone *et al.*, 1997).

If pinger sounds were aversive to dugongs, and if dugong use calls to relay stress, dugong vocalization rates may have increased while pingers were active. Other marine mammals use sound to relay stress (e.g. Caldwell, Haugen & Caldwell, 1962) and solitary captive dugongs have been heard producing stress calls (Nair & Lal Mohan, 1977; Marsh, Spain & Heinsohn, 1978). However, in our experiments, pingers had no effect on the likelihood of dugongs vocalizing, suggesting that pingers do not induce stress calls from dugongs. Vocalizations may also serve to enhance herd cohesion in dugongs (Anderson & Birtles, 1978), and, as with bottlenose dolphins (Smolker, Mann & Smuts, 1993), may be an important method of maintaining mother–calf relationships. Pinger noise potentially masks calls between individuals (Richardson *et al.*, 1995), forcing animals to increase call intensity (and thus the energy needed to make the calls) so that they can be heard above the noise (Scheifele *et al.*, 2005). We were unable to determine the intensity of the calls we recorded, or whether the intensity changed in response to

the pingers. Further studies on the function and intensity of dugong vocalizations would enhance our ability to determine the effects of anthropogenic noise such as pingers.

Effectiveness of pingers and the perception that pingers have addressed the bycatch problem

Implementation of pingers in fisheries before testing their efficacy might lead to the erroneous assumption that the bycatch problem has been resolved (Dawson *et al.*, 1998), and compromise management relations with fishers if pingers are consequently shown to be ineffective. Our experiments indicate that neither 4 nor 10 kHz pingers would reduce the bycatch of dugongs in gill nets by either keeping dugongs away from the area around nets or increasing the likelihood of dugongs detecting the net. To date, seven dugongs have died in shark control nets equipped with 10 kHz pingers (Greenland & Limpus, 2005; B. Lane, 2006, pers. comm.). On the basis of one anecdotal observation of a dugong group avoiding nets equipped with 2.9 kHz pingers, McPherson *et al.* (2004) claim that lower frequency pingers have the potential to reduce dugong entanglements. However, the pinger types we tested are within the frequency range of dugong vocalizations (3–18 kHz, Anderson & Barclay, 1995), which is indicative of optimal hearing sensitivity (Wartzok & Ketten, 1999), and an audiogram conducted on one captive dugong in Australia suggesting a minimum hearing range of 4–32 kHz (D. Ketten, 2000, pers. comm.).

The novel sound of pingers may induce dolphins to investigate their surroundings by activating their sonar and thus detect a net (Dawson, 1991). Dugongs are considered incapable of producing ultrasonic sound (D. Ketten, 2000, pers. comm.), and their investigative response is likely to be visual. Anderson's (1981) field observations suggest that a dugong's underwater vision is equivalent to a mask-equipped diver. However, we did not detect a change in dugongs' orientation to investigate active pingers, suggesting that pingers would not alert dugongs to the presence of a net. In contrast to our experimental situation, dugongs commonly occur in turbid waters reducing the likelihood of pingers inducing a visual investigative response.

If dugongs learned that the sound of pingers represents danger, this sound could act as a stimulus to avoid the surrounding area. Marsh *et al.* (2005) noted that dugongs appear not to have learned to avoid shark nets set for bather protection in Queensland since the 1960s because: (1) their capacity to learn from other animals is limited because studies to date suggest that mother–calf pairs are the only stable social groups (Hodgson, 2004), (2) the rate of successful releases of dugongs from nets is low, (3) the catch is not biased towards young animals as expected if dugongs learned from experience. Dugongs may be even less likely to learn to avoid commercial mesh nets, which are moved constantly, in contrast to shark nets, which remain in position for long periods.

Table 2 Assessment of the state of knowledge on the potential effectiveness or adverse effects of pingers on the species commonly caught in gill nets and shark control nets in Queensland, Australia

Species	Evidence for reduced bycatch	Adverse effects
Humpback whales <i>Megaptera novaeangliae</i>	Yes. ^a	Increased risk through aggressive response ^b
Australian snubfin dolphin <i>Orcaella heinsohni</i>	Not studied.	Not studied
Indo-Pacific humpbacked dolphins <i>Sousa chinensis</i>	No. ^c Have been caught in nets with pingers ^d	Not studied
Bottlenose dolphins <i>Tursiops</i> sp.	No. ^e Have been caught in nets with pingers ^d	Increased risk through aggressive response ^{d,f}
Dugongs <i>Dugong dugon</i>	No. ^h Have been caught in nets with pingers ^g	Unlikely ^h

^aLien *et al.* (1992), ^bMcPherson *et al.* (2001), ^cPeddemors *et al.* (1999), ^dMcPherson *et al.* (2004), ^eCox *et al.* (2003), ^fReeves, Read & Notarbartolodi-Sciara (2001), ^gGreenland & Limpus (2005); B. Lane (2006, pers. comm.) ^hThis study.

Our experiments suggest that pingers will be ineffectual in reducing dugong bycatch. Thus, fisheries agencies risk compromising their relationships with fishers by promoting pingers as a solution to the bycatch problem. The expense of pingers and difficulties enforcing compliance limit their usefulness in developing countries (Peddemors, 1999). Other conservation measures, such as area closures, gear changes, education and awareness programmes offer more reliable solutions for reducing dugong bycatch. Such measures are being implemented in Australia particularly in the Great Barrier Reef Marine World Heritage Area (Marsh, 2000; Fernandes *et al.*, 2005).

Problems with relying on animals to change their behaviour to reduce multi-species bycatch

Technological solutions for reducing human-induced mortalities of animals are attractive because they allow stakeholders to continue their activities relatively unimpeded. However, many of these solutions rely on altering the behaviour of the target species, and thus their effectiveness cannot be assessed without understanding the behaviour of these animals, a demanding requirement where there are multiple bycatch species. Potential solutions such as pingers should only be considered effective if they both: (1) reduce entanglements of at least one species, (2) have no adverse effects on populations of any other species of concern.

Information on the effectiveness and potential impacts of pingers on the five main marine mammal species caught in gill nets in Queensland is presented in Table 2. Humpback whales (Lien *et al.*, 1992) are the only species for which there is evidence that pingers may be effective. However, recent observations suggest that pingers could increase risk of entanglement of both humpback whales (McPherson *et al.*, 2001) and bottlenose dolphins (Cox *et al.*, 2003; McPherson *et al.*, 2004) by stimulating aggressive responses. There is no knowledge of how Australian snub-finned dolphins *Orcaella heinsohni* respond to pingers, while Indo-Pacific humpbacked dolphins *Sousa chinensis* showed a limited response in South Africa (Peddemors, de la Mere & Keith, 1999) and

have been caught in nets with pingers in Queensland (McPherson *et al.*, 2004). All this evidence suggests that it is inappropriate to enforce the use of pingers in Queensland.

Even if pingers were proven effective for some species and benign for others, the long-term effectiveness of behaviour-based solutions is limited by the flexible nature of mammal behaviour. For example, although pingers were shown to reduce harbour porpoise bycatch (Kraus *et al.*, 1997; Trippel *et al.*, 1999; Gearin *et al.*, 2000), one study indicates that this species may habituate to pinger noise, suggesting that pingers may lose their effectiveness over time (Cox *et al.*, 2001). Similarly, changes in environmental conditions, such as a food shortage, may alter the animals' motivations, forcing them to tolerate aversive pinger noise to access food resources. Alternatively, animals could become sensitized to pinger noise, increasing their response over time with prolonged exposure to pingers (Richardson *et al.*, 1995), increasing the potential for displacement from critical habitats. Short-term experiments such as ours are unable to test for such effects. These potential long-term changes in animal behaviour necessitate monitoring of the effects of pingers over time to ensure that the desired positive effects continue and no adverse effects arise (Dawson *et al.*, 1998). Solutions that rely on changing animal behaviour are not guaranteed long-term solutions, an important consideration for fisheries managers when faced with the choice of changing the behaviour of the fishers or the bycatch species.

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