



Acoustic alarms elicit only subtle responses in the behaviour of tropical coastal dolphins in Queensland, Australia

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ABSTRACT: Incidental bycatch in gill nets is the most serious of the global threats to marine mammals. Consequently, many management agencies wish to implement practical and efficient bycatch mitigation systems that both protect species of conservation concern and are readily adopted by fishermen. Australian snubfin *Orcaella heinsohni* and humpback dolphins *Sousa chinensis* occur in small fragmented populations along most of the remote coast of subtropical and tropical Australia, where they are caught in gillnet fisheries operated from small vessels. We experimentally investigated whether a commercially available acoustic alarm modified the behaviour of each of these species in the absence of a net. The movements and behaviour of both species changed subtly when the pingers were active, but the likelihood of the animals leaving an area was not significantly different from the controls. Our results suggest that this technological approach may not be effective in reducing the bycatch of these species. We suggest that further experimentation is unlikely to be cost effective and that government agencies should work with fishers and scientists to explore alternative mitigation measures.

KEY WORDS: Snubfin · Humpback · Dolphins · Behaviour · Pinger · Bycatch · Gillnets · Australia

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INTRODUCTION

Thousands of marine mammals are caught each year as fisheries bycatch (Read et al. 2006). Bycatch has a significant impact on many populations of small odontocetes, including harbour porpoises *Phocoena phocoena*, bottlenose dolphins *Tursiops* spp., Franciscana dolphins *Pontoporia blanvillei*, Hector's dolphins *Cephalorhynchus hectori*, Maui's dolphins *C. hectori maui*, Indo-Pacific humpback dolphins *Sousa chinensis* and the vaquita *Phocoena sinus*.

In Australian waters, all cetaceans are protected under the federal Environmental Protection and Biodiversity Conservation Act 1999 and relevant state legislation. Nonetheless, incidental bycatch in gillnets, including shark nets set for bather protection by the Queensland Shark Protection Program (Gribble et al. 1998), remains a direct threat to populations of marine mammals, especially in coastal waters (Ross 2006). The impacted species include the sympatric Australian snubfin dolphin *Orcaella heinsohni* (hereafter referred to as snubfin

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dolphin) and the Indo-pacific humpback dolphin (hereafter referred to as humpback dolphin), both of which are considered Near Threatened by the IUCN (2011). The snubfin dolphin is apparently endemic to the waters of the Sahul shelf (Beasley et al. 2005, I. Beasley pers. comm.), and it is likely that Australian populations of the humpback dolphin are also genetically distinct and may be a separate species (Frère et al. 2011). At a national level and within the Great Barrier Reef World Heritage Area, both snubfin and humpback dolphins are considered priority species for conservation (Great Barrier Reef Marine Park Authority 2000, see also 'Action Plan for Australian Cetaceans' in Ross 2006).

The Queensland Government maintains an accessible online marine wildlife stranding and mortality database (StrandNet). The programme produces annual reports (e.g. Haines & Limpus 2001, Greenland & Limpus 2005) that record reported catches of both species in commercial gill nets and shark nets set for bather protection. As these reports are largely from populated areas and the key bycatch fisheries range widely, have limited observer programmes and have no incentive to report bycatch, StrandNet underestimates the actual bycatch by an unknown amount (Department of Environment and Resource Management: <https://www.derm.qld.gov.au/strandnet/application>). Numbers reported by the Shark Control Program should be reliable, as its contractors are required to lodge daily returns and receive regular training in species identification. Since the mid-1990s, StrandNet has reported the mortality of 14 humpback dolphins and 6 snubfin dolphins in Shark Control Program nets, all of which had Fumunda F10 type pingers attached (W. Sumpton pers. comm.). Even this low level of gillnet mortality recorded is a cause for concern, as local populations of these 2 species are small (low hundreds or fewer; Parra et al. 2006, Cagnazzi 2010), fragmented and potentially genetically isolated (Cagnazzi 2010). Preliminary calculations using the Potential Biological Removal method (Wade 1998) and population estimates in Cleveland Bay near Townsville (19° 13' S, 146° 48' E) (Parra et al. 2006) indicate that the local snubfin and humpback populations are so small that the sustainable anthropogenic mortality is $<1 \text{ ind. yr}^{-1}$ for each species.

The Queensland government is trialling several approaches to mitigate the bycatch of marine mammals in coastal waters, especially the bycatch of humpback and snubfin dolphins and dugongs

Dugong dugon. These approaches include attempting to change the behaviour of the bycatch species using acoustic alarms or pingers to warn animals of the presence of nets (Gribble 2006). This approach is based on assumptions such as the ability of the pingers to (1) deter each of these 3 species of concern from fishing gear and (2) have no negative effect (such as displacing animals from key habitats) on any species in acoustic contact with these devices (Perrin et al. 1994). As pointed out by Hodgson et al. (2007), responsible implementation of acoustic alarms to reduce marine mammal bycatch should only be considered if pingers can be shown to reduce entanglements of at least 1 species and have no adverse effects on any other species of conservation concern (Hodgson et al. 2007). There are a series of challenges when testing these requirements, which include (1) pseudo-replication (the same dolphin and its response may be inadvertently counted more than once) (Dawson & Lusseau 2005), (2) the low statistical power associated with low levels of interaction (Dawson et al. 1998), (3) the possibility of dolphins habituating to the acoustic signal emitted by the devices (Dawson et al. 1998) (habituation defined as 'a reduction in response over time as individuals learn that there are neither adverse nor beneficial consequences to a stimulus'; Thorpe 1963, cited in Bejder et al. 2006, p. 1155) and (4) the ethical difficulty of testing the efficacy of pingers on nets with appropriate 'control nets' (Teilmann et al. 2006).

Pingers have been shown to reduce the bycatch of species such as harbour porpoises (e.g. Kraus et al. 1997, Laake et al. 1998, Larsen & Krog 2007), Franciscana dolphins (Bordino et al. 2002) and short-beaked common dolphins off the coast of California, USA (Barlow & Cameron 2003). Nonetheless, acoustic alarms do not elicit the same response from all other marine mammals. For example, active and passive acoustic deterrents had little to no effect on net entanglement of Dall's porpoises *Phocoenoides dalli* (Hatakeyama et al. 1994). Common dolphins off the coasts of Ireland were apparently unresponsive to the presence of different pingers lowered from a vessel (Berrow et al. 2008), while pingers have induced subtle behavioural changes in bottlenose dolphins rather than an avoidance response (e.g. Cox et al. 2004).

While there is some evidence that pingers can function as a multi-species solution to reduce bycatch in open-water fisheries (e.g. Barlow & Cameron 2003, Carretta et al. 2008), less evidence exists in coastal waters. Nonetheless, the use of these devices is

potentially attractive to Queensland fishermen because they have been subject to extensive area closures and structural adjustment as a result of the declaration of Dugong Protection Areas in the mid-1990s (Marsh 2000) and the subsequent rezoning of the Great Barrier Reef Marine Park (Fernandes et al. 2005). Regardless of the attractiveness of pingers to fishers and the interest of the Queensland Government in implementing these devices, there has been no formal assessment of their effectiveness in reducing the bycatch of humpback and snubfin dolphins. Experimental studies show that pingers do not significantly affect the behaviour of dugongs (Hodgson et al. 2007), and dolphins have been caught in shark nets set for bather protection and fitted with pingers (Berg Soto 2012) as mentioned above. Thus, research independent of the fishery is also needed to evaluate the potential for acoustic deterrent devices to further reduce the bycatch of humpback and snubfin dolphins by this industry.

Three main methods to test pingers as tools to reduce the bycatch of small cetaceans in gillnet fisheries are recognized (e.g. Dawson et al. 2013, this Theme Section): (1) controlled experiments in commercial gillnet fisheries (e.g. Bordino et al. 2002, Barlow & Cameron 2003); (2) observations of bycatch rates in fisheries in which pingers are used as part of a mitigation strategy (e.g. Carretta et al. 2008, Palka et al. 2008); and (3) studies of the behaviour of marine mammals around pingers or gillnets (e.g. Stone et al. 1997, Cox et al. 2004, Leeney et al. 2007). The first approach is impractical in fisheries in which bycatch levels are very low, as large-scale tests are needed in such circumstances (e.g. Dawson et al. 1998). The second approach requires a comprehensive and costly observer programme in an already existing pinger mitigation system and is difficult to implement in a fishery that operates out of small boats in remote areas with limited observer coverage, such as in Queensland. It was impractical and/or unethical for us to use either of the first 2 approaches. Thus, we used an experimental approach to study the behaviour of both Australian humpback and snubfin dolphins and their responses to commercially available 10 kHz frequency pingers in the absence of a net. Our experiments were designed to provide some of the evidence required to inform managers and stakeholders about the likely efficacy of using acoustic alarms to reduce the bycatch of Australian humpback and snubfin dolphins in commercial gillnets and nets set to protect bathers from sharks in Queensland.

MATERIALS AND METHODS

Study sites

Humpback dolphins were studied in the Rainbow Channel near Amity Point (27° 23' S, 153° 26' E), North Stradbroke Island in Moreton Bay Marine Park, Queensland, Australia, between September 2007 and April 2008. Snubfin dolphins were studied in known areas of dolphin habitat (Cagnazzi 2010), in the mouth of the Fitzroy River (23° 31' S, 150° 53' E) in Keppel Bay, central Queensland, Australia, between July and August 2010.

Pingers tested

Commercially available pingers come in a range of fixed and variable frequencies. All of our tests were made using Fumunda acoustic alarms supplied by the manufacturers at the suggestion of Queensland Government officers. These pingers emit regular interval pulses of 300 ms every 4 s with a fundamental frequency of 10 kHz and a minimum sound pressure of 132 dB re 1 μ Pa at 1 m. As required by James Cook University Animal Ethics Permit no. A1150, we did not mount the pingers on a net to avoid possible animal entanglement.

Calculating the sound propagation of acoustic alarms and deterrents is extremely complex, as the sound field is highly dependent on factors such as habitat morphology and depth of source and receiver (Shapiro et al. 2009). Research by Shapiro et al. (2009) found local variation in the sound field of all sources studied in each of the environments tested. Acknowledging the variability of sound fields and the complexity of studying them, we needed to ensure that the dolphins we considered were within the sound fields of the pingers tested. Thus, the design of our fieldwork was based on the results of tests performed by Baldwin (2002) in the same (sandy bottom) or similar (silty-clay bottom) coastal Queensland waters as our study sites. Baldwin (2002) found that a BASA pinger (acoustic alarm manufactured by BASA and used in Australian waters: 10 kHz; 133.2 dB re 1 μ Pa at 1 m) propagated farther in the sandy bottom environment (i.e. Moreton Bay) than in a silty-clay bottom environment (i.e. Hinchinbrook region). The zone of audibility is commonly defined as the range where the source pressure level remains 20 dB higher than the ambient noise (Richardson et al. 1989). Assuming an ambient noise level of 80 dB, the audible range of a BASA pinger should be

approximately 60 m in a silty-clay bottom environment and 100 m in a sandy bottom environment (Baldwin 2002). Our measurements suggest that the range of audibility of our Fumunda pingers was approximately 100 m along the flow of the Rainbow Channel, Moreton Bay. This value is similar to that calculated by Baldwin (2002). We assumed Baldwin's (2002) estimates of pinger propagation in a shallow silty-clay environment (60 m) to be a reasonable approximation of the sound field for the Fumunda pinger in Keppel Bay, an environment similar to the Hinchinbrook region. This assumption was not tested empirically.

Vessel-based behavioural and acoustic observations

We studied the behavioural responses of humpback and snubfin dolphins to the presence of pingers by comparing their surface and acoustic behaviours during sequential treatment trials from a research vessel.

Vessel transects were conducted at both study sites in search of dolphin schools. Schools of dolphins were defined as either (1) a solitary animal or (2) a group of dolphins where a member was within 10 m of any other member and where over 50% of the animals exhibited the same behavioural state (Smith 2000). Once a school was detected, the vessel was hooked to a mooring buoy and data were collected. In addition to information on species identification and school size, we recorded both surface and acoustic behaviours before, during and after immersing a pinger from the same vessel through sequential treatments, as detailed below.

Behavioural observations of dolphin schools made from our vessel included (1) behavioural states, (2) behavioural events and (3) vocalisations. Behavioural states were recorded every 3 min through predominant group-activity sampling (Mann 1999) and were classified according to the following definitions based on Van Parijs & Corkeron (2001) and Parra (2006):

Foraging: Dolphins engaged in long dives (preceded by a tail-out dive or a peduncle dive), and rapid acceleration at the surface, indicative of animals chasing fish. It includes observations of animals seen directly pursuing a fish (e.g. fish jumping at surface) or with fish in their mouth.

Travelling: All members of the studied group moved in the same direction and speed, spaced within a few body lengths of each other, with shallow immersions between breaths.

Socializing: Animals were involved in active surface behaviour (frequent surfacing and breaching) that included physical interactions among group members and aerial behaviour. Behavioural events observed during socializing included different types of jumps, head bumping and rolling.

Milling: Dolphins showed little movement, tended to remain in the same place and either spent long periods floating at the surface or surfaced asynchronously.

Behavioural events were recorded through continuous sampling (Mann 1999) and included all observed instantaneous surface behaviours, independent of whether they helped describe the overall behavioural state. These behavioural events included mainly jumps, dives, breaches and rolls (Martin & Bateson 1993).

At the same time as the behavioural observations, a single hydrophone (High Tech model HTI-96-MIN, sensitivity: -170 dB; -165 dB re: $1 \text{ V } \mu\text{Pa}^{-1}$) was submerged from the side of the vessel into the water at 3 m depth. Dolphin vocalisations were recorded using an M-Audio Microtrack I (frequency response: 20 Hz – 20 kHz \pm 0.3 dB). Wave files were recorded at sampling rate of 44.1 kHz (24 bit) on a single channel.

Acoustic analyses

Recordings were analysed as spectrograms (512 point FFT, 22 kHz bandwidth) using Raven v1.3, Cornell University Bioacoustics Laboratory (Charif et al. 2007). Only recordings with good signal-to-noise ratio were included, on the basis of aural and visual inspection of the sound and spectrogram (Rendell et al. 1999). Vocalisations were divided into 3 acoustic categories: broadband clicks, burst pulses and narrowband frequency-modulated sounds (whistles). Initial qualitative categorisation of the vocalisations was undertaken using a double blind, independent observer method. The independent observer was provided with a subsample of the entire catalogue, consisting of 61 snubfin and 74 humpback dolphin sound files. Sound files of whistles, burst pulses and clicks were randomly sorted and re-labelled based on an arbitrary consecutive numbering system for each species. The second observer had no information about the vocalisation types, recording context or dolphin identity. The same acoustic software (Raven v1.3) and spectrogram parameters used in the original classification of the vocalisations were used by the second observer. The re-classified vocalisations were

then compared with the original classification to determine the number of common vocalisation types classified by both observers (Rehn et al. 2010).

Experimental treatments

Following Hodgson et al. (2007), we used a series of sequential experimental treatments to investigate the surface and acoustic responses of animals to a single pinger. The duration of each treatment was 10 min for humpback dolphins and 5 min for snubfin dolphins. This difference reflected the difficulties in approaching the elusive snubfin dolphins. The sequential treatments conducted were as follows: (1) Pre-condition: a 10 kHz frequency pinger was held out of the water (the pinger activates only when submerged) (control), (2) During-condition: the pinger was introduced in the water from the side of the vessel and (3) Post-condition: the pinger was removed from the water while observations continued. Observations ended when the dolphin group left the vicinity of the vessel or the experimental period was complete.

To determine whether the dolphins' surface and acoustic behaviours changed as the result of ensonicification (defined as the process of applying sound to an object), 11 behavioural measures were analysed for each 5 or 10 min trial period: (1) percentage of time foraging, (2) percentage of time travelling, (3) percentage of time socializing or (3b) milling (snubfin dolphins), (4) rate of active surfacing, (5) rate of blows, (6) rate of dives, (7) rate of other behavioural events (i.e. jumps, fin displays, chasing and physical contact), (8) rate of whistles, rate of burst pulses, rate of clicks and percentage of time vocalising (5 s scale).

To reduce the dimensionality of the behavioural measures, principal component analysis was simultaneously performed on a correlation matrix of all 11 behavioural measures. Values greater than -0.5 and less than 0.5 were not considered highly correlated with any factor (Field 2000). Friedman's test was then used on the varimax rotated principal components to investigate whether the computed scores for the principal components changed significantly between the pre, during and post treatments. Friedman's test is a non-parametric test (distribution-free) used to compare observations repeated on the same subjects. Once dimensionality was reduced, we applied simpler univariate post hoc procedures where appropriate, to find when significant change may occur between the treat-

ments. Thus, in trials where Friedman's test showed significant differences among treatments, paired sign tests were used with an appropriate Bonferroni correction factor to maintain a familywise error rate of 0.10 (Conover 1999).

Land-based observations (humpback dolphins only)

We measured changes in the movements of humpback dolphins around a pinger array, using land-based observations to test the capacity of pingers to alert or deter animals from a simulated gillnet. This last approach was not conducted for snubfin dolphins because of the absence of a convenient land platform adjacent to their habitat in Keppel Bay.

We measured the closest point of approach by humpback dolphins to a line of 3 pinger moorings across the Rainbow Channel. The shoreline of the Rainbow Channel consisted of a rock slope for the first 2 m to a depth of 5 m, before dropping off steeply to between 10 and 15 m depth. The study area was restricted by the presence of both sandbars and artificial reefs on all 3 sides, limiting the visual field to approximately 130° (between 230° and 360° compass bearing). The 3 Fumunda pingers were submerged at a depth of 5 m from floating buoys anchored to the seafloor and placed 50 m apart from each other and the shore. The pingers were aligned across the navigation channel and in front of the observation platform from where the animals were tracked. On randomly selected days, pingers were either active or inactive (control: batteries were inserted backwards).

This site lacked a high observation point from which to take long-distance readings through traditional theodolite tracking such as that conducted by Cox et al. (2004) and Culik et al. (2001). To simplify analysis, a videolite system was used to track the movements of the dolphins around the pinger array when they were in the focal arena in front of an onshore observation platform overlooking the study site. The videolite combined a video camera (Canon XM2) attached at a fixed angle to a theodolite (Leica TC407). While the camera followed and recorded the group as it moved across the study area, the theodolite measured the bearing of the camera every time a dolphin surfaced. The movement-tracking software Cyclopes (E. Kniest, University of Newcastle, Australia) matched the angles obtained by the theodolite to exported frames from the time-coded footage. The software computed the vertical angle of the surfacing

dolphin by calculating the distance between the animal and the horizon on the exported frame. The program triangulated the position of the animal, by incorporating the constant camera depth of field, and the height and position of the platform. Tide heights were incorporated into the program's clock, for accurate triangulation at any time of the day.

To study the effect of pingers on the movements of humpback dolphins, we compared the following parameters between days when the pingers were active and non-active as follows: (1) number of groups present per day (*t*-test); (2) minimum distance between a surfacing animal and the closest pinger (*t*-test); and (3) proportion of days when dolphins crossed the array at least once (Fisher's exact test). To avoid pseudo-replication, 1 value was extracted for a single day, rather than considering every dolphin track (Dawson & Lusseau 2005).

RESULTS

Vessel-based observations

Humpback dolphins moved quickly and erratically in relation to the research vessel in the Rainbow Channel. During 21.5 h of interactions, we conducted 138 trials on 94 groups with a total of 221 dolphins (mean group size = 2, range = 1–10). Dolphins were visible for at least the control and pinger active phases for 31 trials (*n* = 75, mean group size = 2, range = 1–4). Three of these trials had poor acoustic recordings (i.e. poor signal-to-noise ratio), leaving 28 trials with at least the first 2 sequential treatments complete (pre and during; *n* = 67, mean group size = 2, range = 1–4). Of these 28 trials, 17 trials included all treatments (*n* = 37, mean group size = 2, range = 1–3).

Snubfin dolphins were much more difficult to find and observe than humpback dolphins. During 19.5 h of research effort in Keppel Bay, we conducted 13 independent pinger trials on 13 groups with a total of 38 dolphins (mean = 2.2, range = 1–5). Animals remained visible long enough to commence the second treatment (pinger deployed) on only 12 trials. From these, 10 trials included all treatments.

Table 1. *Sousa chinensis*. Rotated factor scores for each behavioural measure considered in the principal component analysis for the first 4 principal factors for Australian humpback dolphins. Values in **bold** were highly correlated with at least 1 of the 4 principal factors (Field 2000)

Behaviour	Index			
	Socializing	Activity/ alertness	Acoustic	Travelling
Percentage of time foraging	0.31	0.60	-0.02	-0.48
Percentage of time travelling	0.03	0.10	-0.05	0.94
Percentage of time socializing	0.82	-0.12	-0.06	-0.07
Rate of active surfacing	0.25	0.76	-0.06	0.23
Rate of blows	-0.19	0.72	-0.03	0.15
Rate of dives	0.52	0.18	-0.02	0.22
Rate of other behaviours	0.90	0.02	0.07	-0.05
Rate of whistles	0.003	-0.15	0.92	0.02
Rate of burst pulses	0.83	0.19	0.24	-0.13
Rate of clicks	0.09	0.78	0.31	-0.21
Percentage of time vocalising	0.16	0.49	0.83	-0.18
Percentage of variance explained	24.2%	22.1%	15.3%	11.9%

Principal component analysis

Data from both species showed that many behavioural measures had medians approaching 0, suggesting that the data were highly skewed and thus supporting our use of multivariate non-parametric statistical analyses.

Humpback dolphins

The scree plot of the principal component analysis suggested 4 main components, each of which made biological sense, and together explained 73.6% of the variance. Table 1 shows the rotated principal component loadings that represent the contribution of each behavioural measure in each component. The first component, termed the 'socializing index', explained 24.2% of the variance and was highly correlated with the percentage of time socializing, the rate of burst pulses and the rate of those behavioural events related to socializing, such as jumps, flips and rolls. Rate of clicks, rate of active surfacing, rate of blows and percentage of time foraging were loaded heavily on component 2, termed the 'activity/alertness index', which explained 22.1% of the variance. The third principal component, the 'acoustic index', was highly correlated with the rate of whistles and the percentage of time vocalising and represented 15.3% of the variance. The fourth component, termed the 'travelling index', explained 11.9% of the variance.

Snubfin dolphins

The principal component analysis generated 5 main components according to the scree plot. These factors made biological sense from a behavioural point of view, and explained 91.1% of the total variance (Table 2). The first component (socializing index) explained 34.2% of the variance and was closely related to the rate of whistles, rate of burst pulses and rate of other behavioural events, such as belly rolling and side flipping. Although we did not directly observe social behavioural states in this species, the variables correlated with this first component are usually associated with socializing behavioural states (Van Parijs & Corkeron 2001), suggesting that this component is appropriately described as a socializing index. The high correlation between rate of dives and this principal component suggested that at least some of the socializing activities of snubfin dolphins were occurring underwater.

Comparison across experimental treatments

Humpback dolphins

The activity/alertness index was the only principal component that changed significantly across treatments at the $p = 0.10$ level (Friedman's test $p = 0.056$). To determine how these treatments differed among themselves, we performed a series of paired sign tests (Conover 1999) for all 3 possible combinations of treatments. The activity/alertness index differed significantly only from pre to post ($p = 0.006$), indica-

ting that the behavioural change persisted after the pinger was removed from the water. Paired sign tests were performed on the behavioural measures highly correlated with the alertness index (i.e. rate of clicks, rate of active surfacing, rate of blows and percentage of time spent foraging) for pre- and post-treatments only, as differences in other treatment combinations were not significant. Changes were significant in most behavioural measures other than blow rates (i.e. rate of active surfacing for pre-post: $p = 0.007$; rate of clicks for pre-post: $p = 0.008$; and percentage of foraging for pre-post: $p = 0.01$): these behaviours decreased with the introduction of the acoustic alarm.

Snubfin dolphins

When we compared the principal component scores for each factor across different treatments (e.g. control, pinger deployed, pinger removed), 2 principal components were found to change significantly among the treatments (Friedman's test at 0.10 significance level; Conover 1999). These components were (1) the acoustic index ($p = 0.001$) and (2) the travelling index ($p = 0.009$). There was little evidence of differences among treatments for the socializing index ($p = 0.975$), milling index ($p = 0.717$) or foraging index ($p = 0.717$).

The acoustic index was the only component that showed significant change from pre to during conditions ($p = 0.007$) and from pre to post conditions ($p = 0.005$) in a series of paired sign tests. These results support the hypothesis that subtle behavioural

Table 2. *Orcaella heinsohni*. Rotated factor scores for each behavioural measure considered in the principal component analysis for the first 5 principal factors for snubfin dolphins. Values in **bold** were highly correlated with at least 1 of the 5 principal factors (Field 2000)

Behaviour	Index				
	Socializing	Acoustic	Travelling	Milling	Foraging
Percentage of time foraging	0.33	-0.13	-0.14	-0.04	0.90
Percentage of time travelling	-0.03	0.04	0.90	-0.08	-0.20
Percentage of time milling	-0.08	0.14	-0.19	0.94	-0.13
Rate of active surfacing	0.20	0.04	0.51	0.78	0.18
Rate of blows	0.39	-0.15	0.76	0.11	0.07
Rate of dives	0.93	-0.02	0.19	0.08	0.27
Rate of other behaviours	0.96	0.03	0.03	0.07	0.19
Rate of whistles	0.96	0.03	0.05	0.07	0.19
Rate of burst pulses	0.83	0.08	0.14	-0.11	-0.06
Rate of clicks	-0.13	0.98	-0.02	0.04	-0.03
Percentage of time vocalising	0.26	0.93	-0.05	0.14	-0.11
Percentage of variance explained	34.2%	17.2%	16.0%	14.1%	9.6%

changes can last from the introduction of an active pinger in the water to after the alarm removal. Additional paired sign tests were performed on the individual behaviours that were highly correlated with the acoustic index to understand which measures are responsible for the change observed in this component. The only behaviour that changed significantly was the percentage of time snubfin dolphins vocalised, which decreased from pre to post conditions ($p = 0.025$).

Land-based observations of humpback dolphins

The sounds emitted by the three 10 kHz frequency pingers did not cause humpback dolphins to flee from the focal observation area. We tracked 84 groups of dolphins through the study area on 20 d (Table 3). Only tracks that contained 2 or more location points were considered. The number of dolphin groups observed per day, the minimum distance observed from surfacing group to a pinger and the number of days in which animals did not cross the pinger array did not differ significantly between days in which the pingers were active or inactive (Table 3).

DISCUSSION

The 10 kHz frequency acoustic alarm we tested evoked only subtle responses in the inshore populations of Australian snubfin and humpback dolphins studied. Snubfin dolphins slightly decreased the time they spent vocalising, while humpback dolphins

slightly decreased the time they spend foraging and their rates of both active surfacing and clicks. These changes occurred once the pinger was introduced and remained after it was removed. The subtle behavioural reactions elicited in these 2 populations of Australian dolphins are qualitatively similar to the reactions of dugongs in Queensland waters to BASA-type pingers (Hodgson et al. 2007).

Some of our other results were also comparable to findings reported in the literature. For instance, bottlenose dolphin vocal activity diminished around acoustic alarms that were pinging continuously (e.g. Leeney et al. 2007). We observed decreased echolocation activity from humpback dolphins once the pinger was introduced in the water. The percentage of time that snubfin dolphins vocalised also declined from pre to post conditions. Reduction in echolocation rates in response to pingers has also been reported for harbour porpoises (Cox et al. 2001), a conclusion supported by our data for both species. Furthermore, a study conducted in the Gulf of Carpentaria, north Queensland, did not find sufficient evidence to suggest that alarms reduced entanglement of marine mammals, but observed clear behavioural reactions from dugongs and some delphinid species (McPherson et al. 2004). Collectively, these studies suggest that even when acoustic alarms are not effective deterrents for small cetaceans, they may alert them to new stimuli and subtly change their behaviour.

The mechanism by which pingers reduce bycatch of some species of cetaceans is poorly understood. Four hypotheses are proposed: (1) the sounds of pingers are aversive and annoy the animals, causing them to avoid the vicinity of the pinger (Dawson 1994, Kraus 1999); (2) pinger sounds alert the animals and encourage echolocation, resulting in the animals detecting the gillnet (Dawson 1994, Kraus 1999); (3) pinger sounds interfere with the animals' sonar (Kraus 1999); and (4) pinger sounds cause an aversive reaction in dolphin prey species and prompt the dolphins to leave the area (Kraus et al. 1997, Kraus 1999). The integrative behavioural approach applied here provided some insights into the likely veracity of some of these hypotheses for humpback and snubfin dolphins. We did not detect the increase in echolocation rates required to support the second hypothesis. Rather, we detected a reduction in the echolocation rates of

Table 3. *Sousa chinensis*. Comparison of movements of Australian humpback dolphins entering the Stradbroke Island, Amity Point study area during days in which pingers were either inactive or active.

Movement index	Pinger inactive (Control)	Pinger active
Number of days	10	10
Number of dolphins	35	49
Number of groups d ⁻¹	4.9 ± 1.12 (0–11) ^a	3.5 ± 0.64 (0–6) ^b
Minimum distance from surfacing dolphin to closest pinger (m)	33.4 ± 9.38 (0–101) ^a	40.8 ± 11.05 (0–96) ^c
Number of days groups crossed between pingers	7	3 ^d
Number of days groups did not cross between pingers	3	7 ^d

^aValues are mean, SE and range; ^b $t = -1.087$, $df = 18$, $p = 0.295$; ^c $t = -0.511$, $df = 18$, $p = 0.616$, ^d $p = 0.179$

humpback dolphins and in the time snubfin dolphins spent vocalising, results that accord with findings of some other species, such as harbour porpoises (Carlström et al. 2009) and bottlenose dolphins (Cox et al. 2004, Leeney et al. 2007). This reaction may be a component of an alertness response, in which the animal reduces vocalisation to better listen for the acoustic source. Animals may reduce echolocation rates and time vocalising as a response to perceived danger, to reduce e.g. predation risk, although doing so may increase the likelihood of a potential entanglement. However, as in dugongs (Hodgson et al. 2007) and bottlenose dolphins (Cox et al. 2004), this effect did not significantly change the movements of humpback and snubfin dolphins, unlike the case of harbour porpoises (Kraus et al. 1997, Laake et al. 1998, Kastelein et al. 2000).

The relevant state and federal management agencies may decide to continue underwriting research on acoustic alarms in an attempt to reduce bycatch in Australian snubfin and humpback dolphins. Nonetheless, we consider that this approach is unlikely to be cost effective, given our results and the capture of both species in shark nets set for bathers protection with pingers attached to the nets (Berg Soto 2012; see also StrandNet: <https://www.derm.qld.gov.au/strandnet/application>). There are currently 6 pinger manufacturers worldwide (Airmar, Aquamark, Ifremer—for trawlers, STM, FishTek and Fumunda; Dawson et al. 2013) with at least 15 different alarms manufactured to date, including devices designed to prevent depredation. A comprehensive study of the efficacy of acoustic alarms to reduce bycatch in Queensland would require a significant number of pinger types to be tested in a range of different inshore habitats (Baldwin 2002) across all marine mammals of conservation concern. Our research took over 300 h of fieldwork to complete tests for only 1 pinger type and 2 species of dolphins. Assuming 10 types of acoustic alarms, we estimate that it could take up to 3000 h to test them all, costing millions of dollars in labour, equipment and transport, and the active collaboration of the commercial gillnetting industry for extensive periods of testing (Barlow & Cameron 2003). As the number of cetaceans caught as bycatch in tropical Australian gillnet fisheries is relatively low at a local scale (Berg Soto 2012), a large number of trials would be required for results to achieve the required statistical power (Dawson et al. 1998). In a study off Zanzibar, Amir & Berggren (2009) recorded 1 humpback dolphin caught in 236 net sets without pingers, while no dolphins

were caught in 224 sets with pingers, a result the authors unsurprisingly concluded was not statistically significant. These results indicate that thousands of trials would be required to have the power to detect a significant result for Queensland populations of humpback and snubfin dolphins. Even if some pingers were found to be effective in reducing dolphin bycatch and their use were mandated, the required enforcement would be extremely expensive for a relative low-value fishery worth \$20 to \$30 million USD yr⁻¹ (Department of Primary Industries & Fisheries QLD 2006), especially as this fishery operates largely from small boats in remote areas with few observers.

Area closures are an effective means of protecting marine mammals from incidental drowning in the Queensland East Coast gillnet fishery. Area closures are not targeted to protect mobile marine mammals at an individual scale, but at a population level, by eliminating the likelihood of bycatch to that proportion of the population that uses the closed area (Grech & Marsh 2008). The implementation of the Dugong Protection Areas (Marsh 2000) and the rezoning of the Great Barrier Reef Marine Park in 2004 greatly expanded the areas where gillnets are limited or prohibited by increasing the proportion of 'no-take' zones from 4.5 to 33% of the 346 000 km² marine park (Great Barrier Reef Marine Park Authority 2003). This rezoning met the commitment that about 50% of high-priority dugong habitats would be closed to commercial fishing activities, including the gill and mesh nets used in the Queensland East Coast inshore finfish fishery (Fernandes et al. 2005). However, the extent to which the current netting operations overlap the habitats of Australian snubfin and Indo-pacific humpback dolphins remains unknown.

Further restricting commercial netting from areas along the urban and remote coasts of Queensland would reduce the risk of bycatch to mobile marine mammals (Marsh 2000, Grech & Marsh 2008, Grech et al. 2008). Nonetheless, such management initiatives could lead to increased netting competition by fishers in unprotected areas as a result of displaced fishing effort from protected areas. This fishery has already been subject to extensive structural adjustment when the Dugong Protection Areas were introduced (Marsh 2000) and the Great Barrier Reef Marine Park rezoned (Fernandes et al. 2005). A better understanding of the distribution of Australian humpback and snubfin dolphins in Queensland is thus necessary for management agencies to evaluate how much of the current network of protected areas overlaps the coastal habitats of these species of con-

servation concern, which are vulnerable to the risk of bycatch. The required survey work could be carried out using rapid assessment techniques at a fraction of the cost of a comprehensive evaluation of the likely efficacy of acoustic alarms.

We conclude that 10 kHz frequency acoustic alarms should not be implemented to reduce marine mammal bycatch in coastal Queensland waters. Comprehensive solutions to bycatch in Australia must consider both the ecological and social context of the issue. Ecological factors include better understanding of the distributions of bycatch species relative to the fishing effort (Grech et al. 2008). Social factors include understanding the culture of small towns and communities who interact with protected species, such as traditional owners and fishers. Lack of this knowledge should not be an excuse to delay management actions, but a direction that can improve management decisions in the future. A long-term solution is most likely to be achieved by working closely with the fishers and other key stakeholders. We conclude that funding would be better spent working with fishers and scientists to develop practical solutions to this bycatch problem, rather than conducting further trials of technology-based solutions such as pingers.

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