ACOUSTIC ALARMS TO REDUCE MARINE MAMMAL BYCATCH FROM GILLNETS IN QUEENSLAND WATERS: OPTIMISING THE ALARM TYPE AND SPACING.

Geoffrey R. McPherson(1)*, Denis Ballam(2), Jason Stapley (1), Stirling Peverell(1), Douglas H. Cato(3), Neil Gribble(4), Chris Clague(1), and Jon Lien(5).

(1) Queensland Fisheries Service, DPI&F, Northern Fisheries Centre, PO Box 5396, Cairns, QLD, Australia
(2) SEANET, Cairns, Australia.
(3) Defence Science and Technology Organisation, PO Box 44, Pyrmont, Sydney, NSW, Australia
(4) Animal Science, DPI&F, Northern Fisheries Centre, PO Box 5396, Cairns, QLD, Australia.
(5) Memorial University, Newfoundland, Canada.

Abstract

To reduce bycatch of marine mammals in Queensland commercial gillnet fisheries, acoustic alarms to warn mammals of the nets to which they are attached, were trialed. Alarms with fundamental frequencies of 2.9 and 10 kHz in 300 msec tone bursts at 130-140 dB re 1 μPa at 1 m were deployed on commercial gillnets in northern Australian waters. Due care must be taken to ensure that the mammals should detect alarms with sufficient time to permit acknowledgement, avoidance, or cautious investigative action in order to prevent net entanglement. A model to relate environmental and propagation parameters with known or inferred animal acoustic abilities was used to assess performance of two acoustic alarms in different gillnet fishery environments. Fishery Observers and industry volunteer observations indicate mammal reactions to 2.9 and 10 kHz fundamental frequency alarms differ between species. Data were insufficient to suggest alarms reduced entanglement, however clear behavioural reactions were observed for dugongs and delphinid species to alarms under specific circumstances. Aggressive behaviour of delphinids toward the 10 kHz alarms were associated by industry with dolphin entanglements in nets within 1 m of 10 kHz alarms, with industry terminating the trials. Departmental ethical policy dictated that the experiment was terminated as a precautionary measure. The 10 kHz alarm tested may not be suited to commercial fisheries.

Introduction

The Natural Heritage Trust, Coast and Clean Seas Programme, identified the reduction of incidental deaths of marine species due in part to gillnet fishing operations as a priority. In Queensland dugong (*Dugong dugon*), Irrawaddy River dolphin (*Orcaecella brevirostris*), and the Indo-Pacific humpback dolphin (*Sousa chinensis*), were perceived to be at risk.

Bycatch reduction of large whales by 3-4 kHz fundamental frequency acoustic devices [1] has remained unchallenged in the literature. The Queensland Shark Control Program has successfully utilized an acoustic strategy to reduce bycatch of humpback whales. Bycatch has remained lower than pre-acoustic alarm times [2], while humpback numbers have increased 8-11% annually over this period [3].

High and low frequency acoustic alarms reduced bycatch of harbour porpoise without influencing the gillnet target species [1,4]. Reduction of delphinid bycatch by high and variable frequency alarms was demonstrated in a number of European fisheries [1].

Despite this, little optimism has existed within sections of the marine mammal advocacy community that active acoustic devices could reduce mammal bycatch, primarily of small cetaceans, from gillnets. Although a study demonstrated 92% bycatch reduction at a cost of US$1 million, uncertainties were claimed for the results as the study had not been replicated [5]. The strongest criticism of bycatch reduction using acoustic methods is that the results of experiments were not statistically significant, although this criticism does not apply to all studies. The 1996 NMFS Acoustics Deterrents Workshop recognised that some fisheries would never have sufficient fishing power to demonstrate statistically whether acoustic alarms could reduce marine mammal bycatch, and suggested that behavioural studies would provide larger sample sizes to determine alarm effectiveness [6].

The other main criticism of acoustic devices was the suggestion that alarm effectiveness might reduce as a result of habituation, i.e. a weakening of response to the stimulus with repeated exposure. Harbour porpoises became ‘habituated’ to the sound of the alarms [4], based on observations that the porpoise surfacing distances around nets with pingers had reduced with exposure time. The unstated presumption was that the end result of habituation is closer proximity and entanglement. However there were no observations that habituation resulted in entanglements.

Indo-Pacific hump-backed dolphins (*Sousa chinensis*) encroached on gillnets when high and variable frequency alarms were fitted, therefore meeting the criteria for habituation while increasing hunting behaviour close to nets [7], yet there was no increase in entanglement rate. Habituation may not necessarily lead to a loss of effectiveness. Behaviour may change as animals become accustomed to the sounds, but may still be aware of the presence of the source. Little fishery experience was available to assess the effectiveness of alarms in southern hemisphere waters on delphinid species or dugong with the exception of work at the Natal KwaZulu Sharks Board [7] and in New Zealand on Hectors dolphin [8].

This project engaged the Queensland fishing industry in a co-operative assessment of the effectiveness of acoustic bycatch reduction alarms for marine mammals in remote locations using project manufactured, 2.9 kHz alarms for fisheries where dolphin and dugong bycatch occurs, and a commercial 10 kHz fundamental frequency alarm for fisheries where dolphin bycatch occurs.

There are little data to determine appropriate positioning of alarms on nets in relation to auditory capacity of marine mammals and background noise [2,3,9]. This study established alarm spacings in commercially fished habitats to achieve a consistent acoustic sound field, or isopleth, of 10 dB above ambient noise sound levels to ensure marine mammals have adequate warning of nets with alarms attached.

Methods

Fishery monitoring

Inshore (0 to 3 nautical miles) and offshore (7 to 25 n. miles including the Queensland Joint Authority Fishery QJA >25 n. miles) gillnet fisheries operate in the Gulf of Carpentaria (GOC) while an inshore gillnet fishery operates in northern east coast waters. All fisheries are directed toward different target species and maintain specific management objectives, however all fisheries use monofilament gillnets and have recorded entanglements of marine mammals.

Between 2000 and 2003 Queensland Fisheries Service (QFS) maintained an Observer presence in the GOC gillnet fisheries. The SEANET organization conducted a voluntary industry-based bycatch monitoring program in the GOC and off the east coast.

Whenever possible QFS Observers deployed acoustic devices on an alternate net set ‘alarm on/alarm off’ basis to assess the effectiveness of the acoustic devices. When QFS Observers were not aboard, industry volunteers were requested to deploy alarms on the same ‘alarm on/alarm off’ basis.

Acoustic bycatch reduction devices

Two acoustic devices were used with fundamental frequencies of 2.9 and 10 kHz, each transmitting a tone burst of 300 ms duration every 4 s. Alarms of both types were tested prior to distribution using a HI TECH® 30 kHz hydrophone and a TEKTRONIX® TDS1002 oscilloscope with Fast Fourier Transform capacity, and used to reference SPECTRA PRO® acoustic analysis software. Device source levels were measured where the range between device and receiving hydrophone was approximately 10 times the wavelength of the acoustic source, and a correction for propagation loss made to 1 m.

In the inshore net fisheries where 1) interaction with dolphins, dugong and humpback whales were anticipated, 2) where water depth was usually <10 m and 3) net deployment was by hand or small hydraulic net reels, a total of 220 2.9 kHz alarms were distributed to 14 volunteers from the GOC and east coast fisheries. Alarms were deployed midway between the surface and the bottom, attached to the net headrope, mesh or footrope as appropriate. Some 2.9 kHz alarms were also deployed on offshore set nets (water depth >20 m).

All 2.9 kHz alarms maintained a minimum source level of 132-135 dB re 1 μPa at 1 m (RMS) for up to 900 hours of operation (battery life extended by a mercury switch). A spectrum of the 2.9 kHz alarm after 500 hours operation is given in Figure 1 showing a fundamental frequency of 132 dB at 2.9 kHz with multiple harmonics. The 2.9 kHz alarms were designed to maximize fundamental and harmonic output.

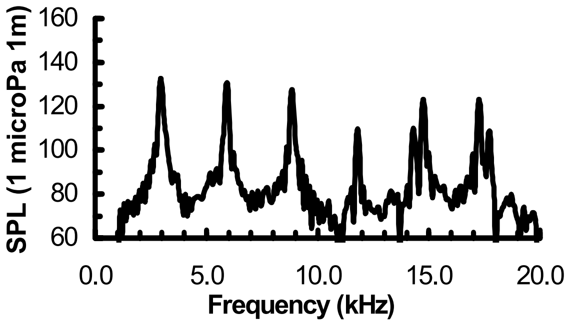

Figure 1. Spectrum of a 2.9 kHz acoustic alarm. (x-axis frequency; y-axis dB re 1μPa at 1 m RMS).

The 2.9 kHz fundamental frequency is within the hearing range of bottlenose dolphins [10], though not at the best sensitivity. There is sufficient sensitivity for the ambient noise to be the limiting factor.

Little is known of the frequency range of hearing of dugongs or humpback whales although it is reasonable to assume that it covers the frequency range of their vocalisations, at least those used for communication. There are descriptions of complex vocalisations of dugong [11] with fundamental frequencies ranging from 500-4,000 Hz. The fundamental was not always the dominant output with maximum signal levels ranging from 2-8 kHz. Captive dugongs in Indonesia detected and initially avoided a 3.5 kHz acoustic alarm (Jon Lien, pers. com.). Frequencies of humpback vocalizations range from 120–4,000 Hz [12,13].

In the offshore fisheries where a) interactions with dolphins were anticipated, b) water depth usually exceeds 20 m and c) nets were deployed with high-speed net haulers, a total of 24 10 kHz alarms were distributed to a single volunteer. These alarms were clipped onto the net headrope or footrope to achieve mid-water deployment. Some 2.9 kHz alarms were also deployed in logistic trials with offshore nets.

All 10 kHz alarms were tested prior to distribution. Manufacturers specifications were a minimum source level of 132 dB re 1 μPa at 1 m at 10 kHz. The unit of measurement, RMS or peak-to-peak, was not specified. The spectrum of a 10 kHz alarm after 500 hours of operation is given in Figure 2, with fundamental output around 10 kHz and little harmonic output.

Of the 15 initial 10 kHz alarms deployed, 33% failed to meet the manufacturers 132 dB 1 μPa at 1 m assumed RMS minimum source level. A source level of a single alarm of 129 dB RMS was confirmed by the Defence Science and Technology Organisation acoustic testing facility.

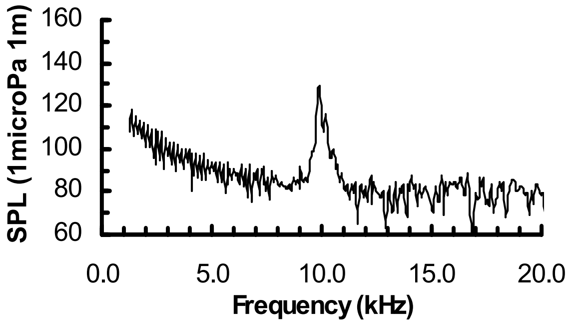

Figure 2. Spectrum of a 10 kHz acoustic alarm. (x-axis frequency; y-axis dB re 1 μPa at 1 m RMS).

Acoustic device spacing

QFS Observers and participating industry operators were requested to position alarms at specific intervals dependant on habitat and the alarm used. Alarm spacing was designed to ensure that the signal would be readily audible at sufficient distance from the net for animals to react in time to avoid the net. This was calculated using the criterion that the alarm signal should be at least 10 dB above the minimum audible signal level, at least 10 m from the net and particularly midway between alarms positioned along the net [9]. The margin of 10 dB represents a substantial increase in loudness relative to the minimum audible level, thus providing a conservative safety factor. An isopleth can be formed around the net indicating the position of the 10 dB margin in aural detection estimated using:

1. The minimum source level of a device after maximum deployment time
2. Acoustic propagation loss for the environment.
3. Ambient noise levels against which the signal has to be detected. This masks the signal and determines the minimum audible signal level. Because of the high levels of ambient noise in the ocean, masking by the noise provides the limit in aural detection rather than the threshold of hearing.
4. The *critical ratio* is the difference in the level of a alarm tonal signal to the background noise spectrum level, at the same frequency at the point at which the signal is just masked by the background noise.
5. Known or assumed hearing sensitivity at the frequency of interest. Some hearing directionality is to be expected at the alarm frequencies that would further enhance the margin of aural detection [9,13].

Propagation loss can be modelled or measured. We use empirical estimates based on measurements in the areas of interest. Ambient noise is quite variable, but is well known for tropical Australia [14,15,16].

The critical ratio is known for bottlenose dolphins [10], but not for humpback whales or dugongs. However, the critical ratio (CR) at a particular frequency shows little variation over the wide range of terrestrial and marine species for which it has been measured [13], so it is reasonable to use these values for humpback whales and dugongs. A CR of 20 dB is assumed for the 3-10 kHz range [13]. As the CR is the point at which a signal should be detected, a 10 dB safety margin is added to generate a CR+10 dB isopleth.

It would be rare for a marine mammal to only make a perpendicular approach to a net. Humpbacks approached alarms to apparently investigate the acoustic source [12], so the line of alarms needs to be effective for animals approaching at any angle. For example, a mammal approaching end-on to the line of the net would not be aware of any two dimensional aspect to the net until it detects the second and subsequent, alarms.

An alarm spacing model [9] was modified to incorporate the distance of detection of acoustic devices behind the one first heard by the approaching mammals (using the margin of CR+10 dB over the minimum level of detection). Hearing directionality would provide some indication of the direction of the second alarm [13]. Bottlenose dolphins have a minimum auditory angle of 2–4° [10]. This angle is not known for dugongs or humpback whales but significant directional capability is to be expected.

Results

Acoustic device spacing

Queensland gillnet fisheries operate in a wide range of biotic and a-biotic acoustic environments. In order to develop a consistent isopleth of the CR+10 dB margin in aural detection, worst-case scenarios for background noise levels were used for both the inshore and offshore fishery areas. This ensures that marine mammals would have adequate warning of nets under all conditions. Ambient noise in Australian waters in the frequency range 2.9–10 kHz would be predominantly from two components: wind-dependent noise (from breaking waves) and snapping shrimp [14,15,16]. Wind-dependent noise is reliably predicted from wind speed (it correlates much better with wind speed than with wave height).

Snapping shrimp generally dominates background levels in waters close inshore, with levels decreasing as depth increases [14,15,16]. The levels vary substantially with position, because of variation in habitat, the shrimps preferring areas where there is cover such as rock, corals etc. Snapping shrimp background levels drop significantly with increasing depth in tropical waters, particularly for muddy substrates where nets may reach the bottom [14,15,16]. Typical spectrum levels for high shrimp concentrations near shore are around 72 dB re 1 $\mu Pa^2/Hz$ at 3 kHz and 68 dB re 1 $\mu Pa^2/Hz$ at 10 kHz. Further off shore in deeper water the levels fall to between 60 and 55 dB re 1 $\mu Pa^2/Hz$ at both frequencies respectively.

Wind-dependent noise, the noise associated with wave action at approximately 20 kts, the upper operating limit of offshore fishing operations in deep waters >20 m, averages about 61 and 53 dB re 1 $\mu Pa^2/Hz$ at 3 and 10 kHz respectively [14,15,16]. Higher wind speeds would result in levels 5 dB or more higher than these values, but nets would not be deployed under these conditions.

Choruses from fish and invertebrates are common around Australia but most of the energy is significantly below 3 kHz [16]. In some areas, the evening chorus may contribute to the noise at 3 kHz.

The ambient noise around a sunken gillnet is influenced by a combination of biological and surface generated noises. The worst case scenario of background noise level for inshore waters <10 m was assumed to be the most conservative at approximately 72 dB re 1 μPa^2/Hz at 3 kHz and approximately 68 dB μPa^2/Hz at 10 kHz, For offshore waters >20 m the levels fall to between 60 and 55 dB re 1 μPa^2/Hz at both frequencies respectively, although given that nets may drift over some shallow areas more conservative levels of 65 and 60 dB at 1 μPa^2/Hz are assumed.

The hearing sensitivity of dugongs and whales are not known. The sensitivity of dolphins is not optimal at 3 kHz although it is slightly lower (better) than ambient noise [10] and would not be a factor in net detection in these worst case scenario conditions.

The acoustic propagation loss used for shallow offshore waters within the inshore fishery area was a transitional model (fitted to measured data [9]) between spherical (initial) and cylindrical (later) spreading rates for variable water depths up to 10 m [13]. With this model the CR+10 dB margin of aural detection would be reached 42 m from an alarm. To achieve this midway between alarms (△) at least 10 m out from the net, alarms should be spaced 78 m apart.

Given a worst case scenario for an under-performing alarm at 132 dB, and ambient noise levels at 72 dB re 1 μPa^2/Hz at 3 kHz, the CR+10 dB margin isopleth around a gillnet with 2.9 kHz alarms at 65 m spacing used for alarm deployment inshore waters <10 m is shown in Figure 3.

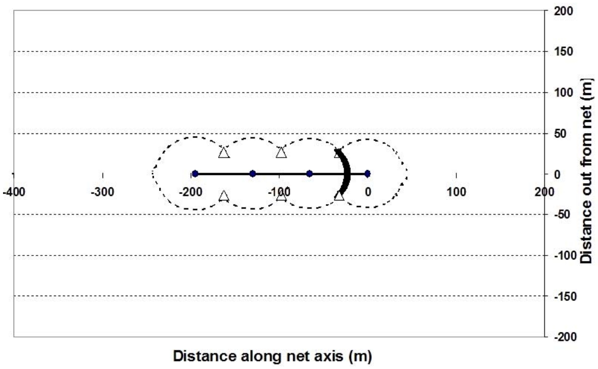

Figure 3. Schematic of the CR+10dB margin in aural detection isopleth around four 2.9 kHz alarms spaced 65 m apart on a net in shallow water <10m. Acoustic propagation shallow water transitional, ambient level 72dB re 1 μPa^2/Hz. (alarms •, CR+10dB mid-alarm position △, CR+10dB from second alarm __)

The CR+10 dB isopleth extends 42 m from each alarm and 27 m from the net mid-way between alarms. For a more conservative alarm spacing on the net of 50 m, the 10 dB isopleth from the second alarm only just falls short of the first alarm for an animal approaching the first alarm parallel to the net (*i.e.* from the right).

Model predictions for 2.9 kHz alarms in shallow inshore indicated that the CR+10 dB isopleth generally extends around an alarmed net in worst case situations and would provide ample warning to whales, dugongs and dolphins of the presence of the alarm and the net to which they were attached. The assumed conditions were conservative, it is unlikely that fishing operations would occur in very shallow hard bottom areas where snapping shrimp would totally dominate ambient noise.

Propagation rates in offshore waters (usually >20 m) where dolphin bycatch has been reported, are assumed to approximate spherical spreading rates [13]. Acoustic device performance in this poor propagation environment would be balanced by slightly lower ambient noise levels.

Given the likely worst case ambient noise levels in offshore waters would be 60 dB at 1 μPa^2/Hz at 10 kHz, the CR+10 dB isopleth around a gillnet in offshore waters is given in Figure 4. The CR+10 dB isopleth for each pinger extends 130 m out from the net. The model indicates that for spacing at 100 m intervals, the CR+10 dB isopleth mid-way between pingers would extend 120 m from the net. The CR+10 dB isopleth for the second pinger extend well beyond the first pinger for a dolphin approaching the first alarm parallel to the net. Delphinid hearing directivity would enhance this signal [11].

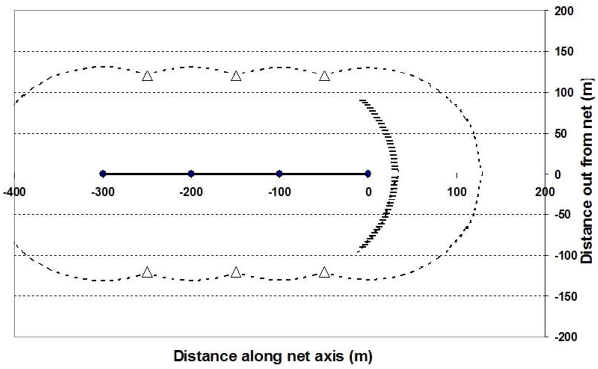

Figure 4. Schematic of CR+10dB margin in aural detection isopleth around four 10 kHz alarms spaced 100m apart on a net in deep water >20m. Acoustic propagation spherical spreading, ambient level 60dB re 1μPa^2/Hz at 10kHz. (alarms •, CR+10dB mid-alarm position △, CR+10dB from second alarm __)

The 2.9 kHz alarms in offshore waters under assumed ambient worst case conditions where alarm spacing was greater that 65 m (namely 100 m) would generate a CR+10 dB isopleth at 73 m from each alarm and at 53 m from the net midway between alarms. Modifying acoustic device spacing on a net set-by-set basis would be difficult to achieve on some net vessels.

The recommended spacing to determine the effectiveness of alarms are approximate and require verification with field recordings for specific habitats. However the estimates are appropriate as an interim as they are the parameters that would provide the most conservative opportunities for mammals to detect the sounds, and the nets to which they are attached.

Marine mammal bycatch monitoring by Observers

Results of trials with 10 kHz alarms on nets in inshore and offshore areas to 25 miles are shown in

Table 1. At an average spacing of every 100 and with the single exception of one set at >200 m, an average of 13 alarms were deployed on every net. There were approximately 1,400 deployments of 10 kHz alarms.

Table 1. Results of 10 kHz alarm deployments in the N3 and N9 fishery areas 2001-2003. Bycatch is the number of entanglements of inshore bottlenose dolphins in / hour / 500 m of net.

Acoustic devices	No. Sets	Soak time hours (avg.)	Avg. net length (m)	Dolphins (Bycatch / h/ 500 m)
ON	105	482.1	1345	2 dolphin (0.0015)
OFF	160	735.9 (4.6)	1199	3 dolphin (0.0017)

Two entanglements of inshore bottlenose dolphins occurred in nets deployed with 10 kHz alarms. One was entangled midway between alarms in the single deployment of alarms set >200 m apart *i.e.* alarms had not been deployed to the 100 m spacing requirements of the Observers. The dolphin may not have detected the alarms at the CR+10 dB isopleth, or considered them to be two non-connected point sources (Figure 4).

The second dolphin entanglement occurred within 1 m of an alarm. The alarm was functioning, and even if operating below manufacturers specifications, should have been readily detected by the dolphin. This entanglement occurred when the CR+10 dB acoustic field existed around a net. There were insufficient data to prove that the 10 kHz alarm type reduced entanglement. Comparable levels of bycatch occurred in nets with/without alarms.

Only 20 nets with 2.9 kHz alarms deployed at 65 m spacing were monitored by fishery Observers in the inshore and offshore areas. A single entanglement of an inshore bottlenose dolphin was noted for a net with a single 2.9 kHz alarm. However the alarm was a single deployment for logistic reasons to test the alarms ability to pass through a net hauler. The dolphin was entangled 400 m from the pinger. At that range it is unlikely that the dolphin would have heard the device even under good conditions.

The 10 kHz alarms were used exclusively in QFS observed gillnet sets in offshore waters within the QJA fishery. Alarms were deployed on 5 sets at an approximate rate of 1 pingered set to 2 non-pingered sets over a two-week period (Table 2). The alarm deployments did not provide any indication that entanglements were reduced. The single observed entanglement of an Indo-Pacific humpbacked dolphin 50 nautical miles offshore expressed as entanglements per hour and per 500 m of net, was in the order of twice that of non-alarmed nets. There is no suggestion the dolphin failed to hear the 10 kHz alarm, it was entangled within 1 m of the alarm.

Anecdotal observations of industry volunteers

Industry volunteers expressed concern to QFS observers that dolphin entanglements occurred at the net adjacent to 10 kHz alarms. Volunteers also

Table 2. Results of trials of the 10 kHz alarm in the Queensland Joint Authority fishery area

Acoustic devices	No. Sets	Soak time hours (avg.)	Avg. net length (m)	Dolphins (Bycatch hour/500 m of net)
ON	5	20 (4.0)	1200	1 IndoPacific (0.0200)
OFF	11	44 (4.0)	1200	1 IndoPacific) (0.0095)

demonstrated to QFS Observers that the 10 kHz alarms suspended from both a stationary, and a moving vessel, evoked aggressive behaviour to the alarm, particularly by larger dolphins, presumably males. QFS Observers recorded the change in behaviour of bow-riding dolphins when exposed to 10 kHz alarms on video. Dolphins immediately moved away when pingers were introduced, then repeatedly attacked the pinger from the side of the vessel, charging in from at least 30 m.

Volunteers deployed 2.9 kHz alarms on 171 nights although generally not on an alternate 'alarm on/alarm off' basis. Industry volunteers believed provision of data could have compromised their operations, only verbal reports were provided.

The 2.9 kHz alarms evoked cautious avoidance responses by dugongs. Industry volunteers from Queensland's east coast observed repeated changes of direction of a group of dugongs when they encountered three nets set perpendicular to their movements. Alarms were positioned at 50 m spacing on short nets. Fishermen must remain in attendance with nets and therefore provide a significant source of observational data, particularly at night when moving dugong would rely more on auditory cues. Unknown delphinids (probably inshore bottlenose), Indo-Pacific and Irrawaddy River dolphins were observed or heard (at night) by volunteers in the vicinity of nets with 2.9 kHz alarms in GOC and east coast fisheries. No aggressive responses were observed toward the 2.9 kHz alarms.

Discussion

The small numbers of gillnet entanglements limit the reliability of any conclusions that can be drawn from the results. There are not enough data prove that either 2.9 or 10 kHz alarms were effective in reducing entanglement of dolphins in commercial gillnets. Entanglements in 10 kHz alarmed nets, expressed as number per hour per 500 m of net, were broadly comparable to nets with no alarms, and higher in the QJA observed sample.

The 10 kHz alarms were withdrawn from testing in commercial gillnet fisheries because industry associated two entanglements within 1 m of 10 kHz alarms as the direct result of aggressive behaviour of dolphins to the alarms. Industry concern was the dolphins adverse reaction to the 10 kHz alarms that brought them into close proximity to gillnets and an increased risk of entanglement. Trials were terminated to comply with departmental animal ethics provisions.

There was no suggestion that the dolphins could not have heard the 10 kHz alarm signal. Delphinid sonar systems would detect monofilament gillnet mesh surrounding an alarm from a range of at least 100 m [10]. The mechanism for the entanglements due to directed aggressive responses to the 10 kHz alarms is not understood. The alarms therefore did not fail, it is the behavioural response that is the problem. Humpbacks also charged some acoustic sources [17].

The industry observation that dugongs responded to multiple closely spaced 2.9 kHz alarms requires further investigation to reduce gillnet entanglement. We further consider that differential responses may exist for single 'one-dimensional' sound sources compared to multiple, 'two-dimensional' sound sources positioned on a net.

Commercial 10 kHz pingers with 'noisy' or strong harmonic signatures did not evoke aggressive responses from delphinid species in North and South American waters despite animals being observed within 5 m of the alarms [18,19]. This 'noisy' 10 kHz alarm and the 2.9 kHz alarm, despite different fundamental frequencies, were shown to have overlapping and substantial harmonic frequencies [8]. They differed markedly from the 10 kHz alarm tested here that generated a very weak harmonic signature up to 60 dB below the fundamental.

Industry volunteers ceased using the tested 10 kHz alarms and requested continued use of the 2.9 kHz alarms, particularly in areas where dugongs and Irrawaddy River dolphins were present. Volunteers expressed confidence that the 2.9 kHz alarms would reduce the likelihood of interactions.

The Natural Heritage Trust part funded this study.

References

1. STECF. Report of the Scientific, Technical and Economic Committee for Fisheries. Incidental catches of cetaceans, 10-14 December 2001, SEC 376, 83p. 2002.
2. Paterson, R and Paterson, P and Cato, DH. "Continued increase in eastern Australian humpback whales 2001, 2002". *Memoirs of the Queensland Museum* 49(2), 712. 2004.
3. McPherson GR, Lien J, Gribble NA and Lane B. "Review of an acoustic alarm strategy to minimise bycatch of humpback whales in Queensland coastal gill net fisheries," *Memoirs of the Queensland. Museum,* 47(2):499-506. 2001.
4. Gearin PJ, Gosho ME, Cooke L, DeLong R, Laake J. and Hughes KM "Experimental testing of acoustic alarms (pingers) to reduce bycatch of harbour porpoise *Phocoena phocoena* in the state of Washington". *Journal of Cetacean Research and Management* 2:1-9. 2000.
5. Dawson SM, Read A and Slooten E. "Pingers, porpoises and power: Uncertainties with using pingers to reduce bycatch of small cetaceans". *Biological Conservation.* 84(2):141-146. 1998.
6. Reeves RR, Hofman RJ, Silber GK and Wilkinson D. "Acoustic deterrence of harmful marine mammal fishery interactions". Proceedings of the Seattle Workshop. March 1966, 70p. National Marine Fisheries Service and Marine Mammal Commission USA. 1996.
7. Peddemors VM, de la Mere S, and Keith M "Indo-Pacific hump-backed dolphin (*Sousa chinensis*) reactions to pingers: implications for effective long-term deployment of active acoustic devices in permanently set coastal fisheries". Paper SC/51/SM28 presented to the IWC Scientific Committee, May 1999 (unpublished). 21pp. 1999.
8. Stone G, Kraus S, Hutt A, Martin S, Yoshinaga A and Joy L. "Reducing bycatch: Can acoustic pingers keep Hector's dolphins out of fishing nets". *Marine Technical Society Journal* 31(2):3-7. 1997.
9. McPherson GR, Cato DH and Gribble NA "Acoustic properties of low cost alarms developed to reduce marine mammal bycatch in shallow coastal waters of Queensland, Australia". Paper SC/51/SM36 presented to the IWC Scientific Committee, May 1999 (unpublished). 16pp. 1999.
10. Au WWL. *The Sonar of Dolphins.* Springer-Verlag, New York. 277pp. 1993.
11. Anderson PK and Barclay RMR. "Acoustic signals of solitary dugongs: Physical and behavioural correlates". *Journal Mammalia* 76(4):1226-1237. 1995.
12. Lien J, Todd S and Guigne J. "Inferences about perception in large cetaceans, especially humpback whales, from incidental catches in fixed fishing gear, enhancement of nets by "alarm" devices, and the acoustics of fishing gear". in. *Sensory Abilities of Cetaceans*. Thomas, J. and Kastelein, R. eds. Plenum Press, New York. p. 347-362, 1990.
13. Richardson WJ, Greene Jr C R, Malme CI and Thomson DH *Marine Mammals and Noise*. Academic, San Diego. 1995.
14. Cato DH "The biological contribution to the ambient noise in waters near Australia". *Acoustics Australia* 20(3):76-80. 1992.
15. Cato DH "Ambient sea noise in Australian waters" Proc. Fifth International Congress on Sound and Vibration, Adelaide, Casual Productions, Adelaide, 5, 2813. 1997.
16. Cato DH and Bell MJ "Ultrasonic ambient noise in Australian shallow waters at frequencies up to 200 kHz". MRL Tech. Rep. MRL-TR-91-23. 1992.
17. Tyack P. "Differential response of humpback whales, *Megaptera novaeangliae*, to playback of song or social sounds". *Behavioural Ecology and Sociobiology* 13:49-55. 1983.
18. Cox TM, Read AJ, Swanner D, Urian K and Waples D. "Behavioural responses of bottlenose dolphins, *Tursiops truncatus*, to gillnets and acoustic alarms". *Biological Conservation* 2: 203-212. 2004.
19. Monteio-Neto C, Avila FJC, Alves TT, Araujo, DS, Campos AA, Martins AMA, Parente CL, Furtado-Neto MAA and Lien J. "Behavioural responses of *Sotalia fluviatilis* (Cetacea, Delphinidae) to acoustic pingers, Fortaleza, Brazil". *Marine Mammal Science* 20(1):145-151. 2004.