Acoustic methods to mitigate bycatch and depredation by marine mammals on commercial fishing operations in Australian waters: Fishermens options.

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ABSTRACT

Interactions between cetaceans/sirenians and commercial fishing gear in Australian waters generate biodiversity concerns with bycatch interactions and depredation product loss interactions impacting on the viability of many fisheries. Despite acoustic capabilities to detect gillnets, continued bycatch mortalities resulted in the development of acoustic alarms/pingers from the late 1980's to alert inattentive/resting animals to the presence of nets during hours of darkness or in turbid water conditions. New depredation mitigation pingers have demonstrated significant reductions in longline depredation and fish trawl entrapment of relevance to Australian fisheries. Developments with early acoustic detection of depredation behaviour will permit fishery operators to take steps to minimise depredation interaction exposure periods and pinger exposure time. Fisheries adapt to benefits demonstrating economic and biologically relevant advantages faster than directed research projects. Where interactions with marine mammals occur, fisheries are encouraged to conduct their own monitoring activities with organisations that share common positive objectives for their fishery.

INTRODUCTION

Bycatch of marine mammals in gillnets and the attempts to reduce its incidence were reviewed by the Special Issue Report No.15 of the International Whaling Commission (IWC) in 1990 (Perrin, Donovan & Barlow 1994). While the IWC addressed acoustic bycatch mitigation methods up to 1990, it considered that much of the active and passive acoustic mitigation effort had also been aimed at reducing depredation by marine mammals on fishing activities. By 2009, depredation reported from coastal and high seas line and net fisheries was still growing in significance causing serious economic and biodiversity ramifications for many fisheries including within the Australian fishing region (McPherson, Clague, McPherson, Madry, Bedwell, Turner, Cato & Kreutz 2008).

Australia experienced its highest ever level of marine mammal bycatch from the Taiwanese gill net fishery for sharks, tunas and tuna-like species that operated between the NW Shelf and the Gulf of Carpentaria from 1974 until mid 1986 (Harwood, McNamara, Anderson & Walter 1984). The fishery averaged 10,000 tonne live weight annually with a total fishery period estimated bycatch of 14,000 dolphins.

The conservation threat generated by fisheries interactions is of concern in Australia where Protected Species legislation exists. Depredation on fishing gear by Protected Species enhanced the risks of negative interactions no matter what the population status of the species involved.

Reference to acoustic alarms/pingers in the literature is somewhat interchangeable although either reference is correct. Alarms were first used in the 1980's to warn humpback whales in Canadian waters using lower frequency signals up to 4 kHz. Pingers were developed in the 1980's for a porpoise species by Japanese researchers in the North Pacific using 10 kHz signals which later were applied for use with dolphins.

The basis of pinger mediated bycatch mitigation in gillnets is that cetaceans/sirenians possess acoustic capabilities, including active sonar detection in dolphins, that match the active acoustic attributes of the pingers. The matches should be,

1) within the animals' peak hearing capability,
2) within the animals' peak vocalisation frequency yet,
3) outside the hearing sensitivity of the target species.

The bioacoustic literature highlights the strengths in toothed whale (in particular) acoustic capability but rarely highlights the known shortfalls of cetacean acoustic capability. Many cetaceans in open water conditions would not be capable of consistently matching experimentally determined and averaged acoustic capability in real-world conditions.

Deployment of alarm types, their output, deployment requirements and effectiveness in Australia are described in McPherson, Lien, Gribble, & Lane (2001), McPherson, Ballam, Stapley, Peverell, Cato, Gribble, Clague & Lien (2004), McCauley & Cato (2003) and Erbe, McPherson & Craven (2011). Pinger use has been limited to date to Queensland Shark Control Programme (QSCP) and NSW Shark Control programme and Queensland commercial fishery use. The Northern Gulf Natural Resource Management (NGNRM) group with funding from NHT2 has facilitated commercial fishery alarm/pinger development and use in Queensland. In total more than 1000 acoustic devices have been placed into commercial fishery use by NHT funded projects, almost five-fold the numbers deployed in any other Australian fishery.

Marine mammal interaction rates are considered to be currently low. However, to meet appropriate fishery sustainability targets the existing low mortality rates must still be reduced on biodiversity and fishery survival grounds.

Acoustic methods offer opportunity to mitigate marine mammal interactions. Unfortunately some research has contributed to the stifling of essential acoustic interaction mitigation work, resulting in the needless mortality of marine mammals in fishing operations and continued criticism of industry activity. The fishing industry should be aware of impediments to responsible pinger use in Australia and what is available internationally to mitigate negative interactions to ensure best outcomes for industry without interference.

BYCATCH MITIGATION PINGERS

Deployments on nets

Alarms/pingers themselves were designed to function to alert dolphins at times of inattention (*e.g*. sleep equivalent) and to the nets they were associated with (Lien, Barney, Todd, Seton & Guzzwell 1992) providing an ongoing association between the pinger and net could be maintained (*i.e.* direct reinforcement). The dolphin behavioural literature indicates that they are capable of associative learning with a reduced risk of entanglement. If there was no reinforcement agent, such as a net between pingers, then there would be no need for a behavioural reaction (McPherson & Gribble 2011). Alert dolphins and porpoises are known to detect holes in nets if present and transit through them if large enough (e.g. Goodson, Klinowska & Bloom 1994).

Recent pinger developments include constant frequency, amplitude modulated, frequency modulated and impulsive signals that demonstrate strong “dissuasive” effects on some dolphin species. Variants include the prototype Aquamark pinger of Leeney *et al*. (2007), later Seamaster Protector pingers (described by McPherson, Clague, McPherson, Madry, Bedwell, Turner, Cato & Kreutz (2008), variant Dolphin Dissuasive Device (DDD) pingers (Nishida & McPherson 2011; Northridge, Kingston, Mackay & Lonergan 2011).

In the Mediterranean (Brotons, Munilla, Grau & Rendell 2008) and US (Read, Waples, Urian, & Swanner 2003) *Tursiops* bottlenose dolphins were not deterred from being in the immediate vicinity of gillnets with bycatch mitigation pingers. There were some differences between the rates at which depredation from nets were mitigated by different pinger types although there was no area exclusion or sign of deterrence from the pingers, just deterrence from entanglement in nets.

Estimating the appropriate spacing distance between pingers on nets is not new. McPherson, Ballam, Stapley, Peverell, Cato, Gribble, Clague & Lien (2004) established alarm spacing requirements for worst-case scenario conditions 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. The acoustic positioning strategy was supported for Australian conditions by McCauley & Cato (2003). The method was consistent with the supportive methodology of Erbe, McPherson & Craven (2011).

Barlow & Cameron (2003) estimated offshore spacing distances for a range of dolphins based on known hearing capabilities of delphinids. Northridge, Kingston, Mackay & Lonergan (2011) described an alternate approach to estimate spacing by monitoring change in bycatch rate as spacing between pingers increased in a commercial fishery situation.

International pinger success

US West Coast.

Barlow & Cameron (2003) summarised the effect of 10 kHz pingers from the Observer data set of the US west coast driftnet fishery. The report included one of the longest continuous monitored fisheries incorporating pingers where the reduction of bycatch of common dolphin and all dolphins were described as statistically significant effects.

US East Coast.

NOAA Harbour Porpoise Take Reduction Plan (HPTRP) in 2009 made pingers obligatory for the Gulf of Maine fishery region. In 2010 NOAA Fisheries announced that pingers would be mandatory for an increased number of US east coast fisheries. A requirement for the fishing industry is that participants attend pinger deployment and utilisation courses conducted under the auspices of NOAA. Read & Waples (2009) determined that 10 kHz constant frequency pingers significantly reduced depredation on gillnet catches of Spanish mackerel in US let alone maintained a negligible bycatch rate. There was no suggestion from Read, Waples, Urian, & Swanner (2003) that the pinger forced the dolphins a specified distance away from the pinger associated nets or caused what some ‘marine mammal’ authors would describe as a deterrence effect to individual Atlantic bottlenose dolphin. The pingers functioned as they were designed; they reduced bycatch. The depredation mitigation was a bonus.

South Africa.

Dolphin mortalities for KwaZulu Natal Sharks Board nets averaged 58 per year for the period 2004-2008 (http://www.shark.co.za/mort2.htm). Mortalities were reported primarily from approximately 40 klm of gillnets. Peddemors, de la Mere & Keith (1999) noted that a Frequency Modulated pinger reduced bycatch of Indo-Pacific humpback dolphin by about 60% in turbid surf conditions while the dolphins slightly partitioned their behaviour within 100 m of the net including increased hunting behaviour. The pinger itself has now been superseded and the pinger spacing may have been more appropriate yet the relevanceof the biological importance of the bycatch reduction was apparent.

Peter & Peddemors (2006) identified reduced bycatch on inshore Indo Pacific bottlenose dolphin with the use of pingers in KwaZulu Natal. The authors suggested enhanced vigilance around nets with pingers, specifically at the pinger. There were concerns about the entanglement within 2 meshes to some 10 kHz pingers, probably Airmar pingers, (Vic Peddemors KwaZulu Natal Sharks Board pers. comm.). Queensland Gulf fishery operators found the same aggressive attacks on Airmar pingers by Indo-Pacific bottlenose dolphins (McPherson, Ballam, Stapley, Peverell, Cato, Gribble, Clague & Lien 2004) and refused to use the pinger type. QSCP continued to use Airmar pingers in their operations.

Pinger spacing in the KwaZulu Natal Shark Programme was at a minimum 140 m with pingers often 70+ m from the end of the 305 m nets (http://www.shark.co.za) in poor sound propagation zones adjacent to the surf zone where multiple lines of nets parallel to the beach overlapped. Pinger manufacturers’ recommended spacing for the pinger types used in low background noise oceanic areas was a minimum 100 m. Spacing of 70-100 m would have been more appropriate based on acoustic monitoring in the surf zone on Queensland’s Gold Coast (McPherson, Cato & Gribble 1999). Erbe, McPherson & Craven 2011) recommended even closer spacing for the same pinger type in surf conditions.

European Commission

Gillnet regulations in European Commission waters are complex although all net deployments are subject to Regulation 812/2004 (Council of the European Union 2004) and S.I. 274 of 2007. The International Centre for the Exploration of the Sea reviewed the bycatch mitigation capability of pingers in EU waters to 2010 and included an assessment of pingers for porpoises and dolphins (ICES 2011),

> Pingers are the most viable method to minimize bycatch, and recent studies have suggested using pingers at wider spacing which would make deployment cheaper for the fisheries involved.

Acoustic pingers reduced dolphin bycatch in driftnet fisheries when they existed (Imbert & Gaertner 2001). Pingers reduced bycatch in a number of phocid porpoise and delphinid dolphin species in gillnets and trammel nets. Northridge, Kingston, Mackay & Lonergan 2011) noted that bycatch mitigation of dolphins, not as numerous as porpoise, did not demonstrate the same robust statistical level as porpoise although this did not suggest the mitigation was not important.

Most marine mammal problems in Mediterranean waters involve depredation mitigation of gillnet catches by bottlenose dolphin. Bycatch is now usually a rare event during daylight fisheries. Several commercial pinger styles are utilised (Brotons, Munilla, Grau & Rendell 2008, Buscaino, Buffa, Sara, Bellante, Tonello, Sliva Hardt, Cremer, Bonanno, Cuttitta & Mazzola 2009), most demonstrating a statistically significant reduction in target fish loss from dolphin depredation behaviour.

South America

Alfaro-Shigueto (2010) utilised a 10 kHz constant frequency tone pinger and demonstrated bycatch reduction of 94% and 73% of offshore dolphins off Peru over two experiments. While the reductions did not meet an artificial 95% significance level the observations would represent a strong cumulative reduction in mortalities. If Alfaro-Shigueto (2010) had accepted the null hypothesis that pingers were not effective as it was not rejected at the 95% significance level, then further fishing in the absence of pingers would have maintained a high level of unacceptable dolphin mortality.

Alfaro-Shigueto (2010) recognised that the 200 m device spacing used *was incorrect* in that pinger spacing was twice what it should have been based on spacing's recommended for the same pinger by Barlow & Cameron (2003). Yet the *incorrec*t 'double spacing' still generated substantial bycatch mitigation rates. Correct spacing's at 100 m for that pinger type may have generated higher bycatch mitigation rates giving a most important biological significance and a statistical significance. The recognition strengthens the argument for non-obligatory hypothesis acceptance in welfare situations, at least for bycatch mitigation of Protected Species.

Zanzibar

A project completed in Zanzibar assessed the capability of 10 kHz pingers to reduce bycatch of Indo-Pacific bottlenose dolphin and humpback dolphin species in drift and set nets. Commercial net fisheries were monitored at a level substantially greater than that currently observed in Queensland waters over an area roughly comparable to Moreton Bay. Amir (2010) concluded that 10 kHz pingers reduced bycatch in offshore drift nets of the same bottlenose dolphin species present and rarely encountered in drift nets in Gulf of Carpentaria waters. A statistical level of significance was experimentally attributed to the bycatch reduction from 257 net sets with pingers and 251 net sets without pingers.

The same statistical level of significance was not attributed to bycatch reduction of Indo-Pacific humpback dolphins in the bottom set gillnet fishery as the data were limited. In this fishery analogous to nearshore and shallow water set net fisheries in Queensland, no humpback dolphins were caught in the sets with pingers and one was caught in net sets without pingers. Population levels of the humpback dolphins were generally considered to be critically low in the area after decades of high intensity fishing effort in such a small area. The bycatch of a single dolphin was considered to be 6.3% of the population in the Menai Bay region therefore the zero catch in nets with pingers was biologically important.

Pinger failures?– A lack of success in fishery applications or was that not really the case?

Semantics

The factor that causes most confusion with descriptions of acoustic pinger effectiveness is the term *deterrent*. An early descriptor of acoustic alarms/pingers (Reeves, Hofman, Silber & Wilkinson 1996) used two definitions of deterrent, a deterrent effect by the pingers themselves or a deterrent from entanglement in nets. Rarely is the latter use considered.

For effective bycatch mitigation, marine mammals must associate the device (McPherson & Gribble 2011) to the net that it is associated with. The association could be formed by eyesight, active acoustic echolocation (dolphins) or passive acoustic listening (dolphins, humpback whales and dugong). More complex associations could include multiple coherent sound sources or the context of the sounds themselves.

In QSCP and commercial fisheries in Queensland and in the US at least, dolphins are known to move in proximity to 10 kHz pingers on nets, hence not recorded as having any deterrent/avoidance behaviour (e.g. Read, Waples, Urian, & Swanner 2003). Soto, Marsh, Noad, Parra & Everingham (2010) made a unilateral assumption that a 10 kHz would be a deterrent to Indo-Pacific humpback and as the dolphins were not moved away from the isolated pinger they informed fisheries agencies that "pingers tested would be ineffective in deterring Australian Indo-Pacific humpback dolphins from nets". The manufacturer of the Fumunda 10 kHz pinger did not refer to the pinger as a deterrent in any way.

Pingers must meet manufacturers' own specifications.

Bache (2003) noted that in addition to concerns about their baseline efficiency, pingers must be properly maintained and that unit malfunction would reduce their effectiveness. The QSCP deployed without testing PICE dolphin pingers in the late 1990's (author, pers. obs.). Defective batteries in all pingers resulted in exceptional dolphin mortalities in the Gold Coast area. The device failure clearly indicated how effective pingers could be if deployed correctly. The deployment was a pinger success and a human failure.

Shortfalls in acoustic capability of commercial alarms/pingers have been noted (McPherson, Ballam, Stapley, Peverell, Cato, Gribble, Clague & Lien 2004; Kastelein, van der Huel, van der Veen, Verboom, Jennings, der Han &

Reijnders 2007, Shapiro, Tougaard, Jorgensen, Kyhn, Balle, Bernardez, Fjalling, Karlsen & Wahlberg 2009; Erbe, McPherson & Craven 2011). In general many pingers tested varied by a minimum 6-25 dB where 6 dB represents a halving of detection range. Such variation would be totally inappropriate for commercial deployment on gear to achieve consistent alerting capability.

Pinger manufacturers should quote minimum performance specifications instead of mean specifications as well as present meaningful directional propagation attributes. The directional propagation of a low frequency whale alarm nominally 3 kHz and 135 dB in Figure 1, was assessed by Erbe, McPherson & Craven (2011). An approaching mammal would experience signals depending on orientation of the pinger that here would range 18 dB. The actual frequency of the nominal 3.0 kHz ranged between 2.6 and 2.8 kHz.

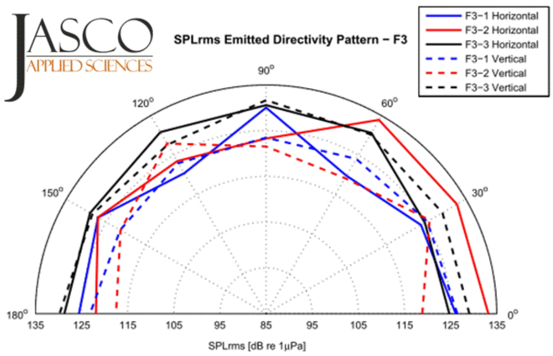

Figure 1. The Source Level (rms) of three Fumunda whale alarms compared between the positions 0-180º in the horizontal and vertical positions. (Source: Erbe et al. 2011).

The detection capability of dolphin sonar to a gillnet is an integration of sonar backscatter from components of a net. The backscatter reflects the dimension of the mesh, the reflectivity of the surface and density of the net mesh and/or ropes, the amount of mesh within the sonar beamwidth and the angle of the net mesh to the sonar beam (McPherson 2010). Variations in the Target Strength of gillnets would weaken any benefits derived from a positive association between pingers and gillnet material. Multifilament cord nets used in the QSCP would likely change over 21 day deployments as water would penetrate mesh material reducing the Target Strength of the nets. Mooney, Au, Nachtigall & Trippel (2007) noted that monofilament net reduced Target Strength with extended soaking. Variation of the net Target Strength would change the association between pingers and gillnet detection therefore placing dolphins at increased risk.

Statistical assessment of pinger effectiveness

The NMFS Acoustics Deterrents Workshop recognised that some fisheries would never have sufficient fishing effort to demonstrate statistically if alarms could reduce marine mammal bycatch. Multiple behavioural studies would provide larger sample sizes to determine alarm effectiveness (Reeves, Hofman, Silber & Wilkinson 1996). Nonetheless most hostile examinations of alarm/pinger use still relate to the improvement in bycatch not achieving predetermined artificial level of significance.

Martı´nez-Abraı´n (2008) observed it was common to find papers in ecology journals where the authors confounded statistical significance with biological relevance, or strength of evidence against the null hypothesis. The concern was that observed strong biological effects without a pre-determined statistical result could lead to wrong scientific conclusions, and to prevent long-term knowledge accumulation in ecology. Where a rare event mammal entanglement appeared to be reduced with a bycatch mitigation strategy (a biologically important event) yet the statistical analysis did not achieve a significant result (at a human determined significance level), then the reason was probably because the sample size was low and should not be viewed as a failure of the bycatch mitigation strategy. Achieving an arbitrary statistical result for a rare event bycatch mitigation would require expansion of the experiment and to place more animals at risk. The World Wildlife Fund has established incremental improvement with ISO 14000 to improve benchmarks and baselines in a number of agricultural and biological programmes reducing the likelihood of achieving statistically significant results.

Pingers may perform well in many instances however, when they are deployed incorrectly, deliberately or accidentally, the experimental result may reflect an ineffectiveness of the pingers. In a review of scientific ethics associated with experiments conducted by scientists with farmers and fishers Wynne (1996) concluded that industry participants should be wary of the conclusions of some scientific findings. Wynne (1996) outlined the criteria for the fishing industry to use to evaluate information provided by the scientific community namely,

- whether or not the provided scientific knowledge actually worked,
- whether the scientists omitted / ignored some information or event of significance,
- that fishermen should investigate the institutional affiliations of the scientists and the objectives of their organisation relative to the fishermen,
- whether the scientists responded to criticism of their advice/reports and were they transparent in dealing with fishermen?

DEPREDATION MITIGATION

Current mitigation approaches

The IWC has long recognised the dual problems of marine mammal bycatch and depredation in association with commercial fisheries and specialised 'fisheries' such as QSCP (McPherson, Clague, McPherson, Madry, Bedwell, Turner, Cato & Kreutz 2008). The Fisheries Research & Development Corporation project (FRDC 2003/016 Toothed Whales) investigated a range of applied methods to mitigate depredation of toothed whales on tuna longline catch. Depredation mitigation by toothed whales on both gillnets and a baited line is a complicated process as outlined by Nishida (2007).

McPherson & Nishida (2010) outlined the developing options for the fishing industry to help mitigate depredation. The methods include Avoidance at long range and Minimisation at close range, both involving passive and active acoustic methods.

Avoidance - Detection.

Depredation is associated with enhanced acoustic communication between individual marine mammals. Detection of the activity is not feasible for the fishing industry using sonobuoy systems based on remote computer acoustic processing capability, power use transmission range and above all cost.

Global Detection Systems is developing a vocalisation detection system for Commercialisation Australia (McPherson & Nishida 2010; McPherson, Clarke, Hingley, McPherson &

Erbe 2011). Detection is based on classification of entropy associated with the toothed whale vocalisations associated with target fish depredation and bait depredation (Figure 2).

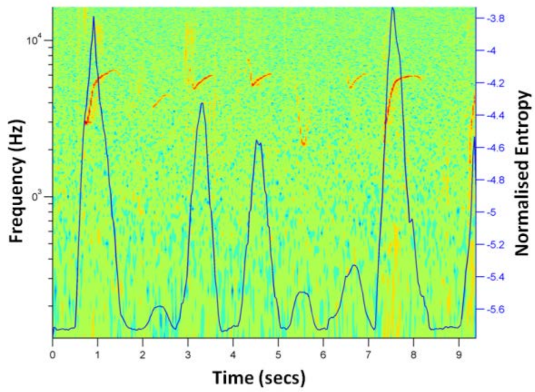

Figure 2. Spectrogram of false killer whale whistles in the Australian Fishing Zone enclosed with a line of normalised Entropy (signal disorder). Detection occurs when the signal organisation (low entropy) exceeds a specified level (Image: Bronson Philippa, Engineering & Physical Sciences, JCU).

Active acoustic interference

DDD pingers have developed for depredation mitigation in longline systems. Nishida & McPherson (2011) described a frequency modulated and broadband sonar interference pinger system featuring random and interactive duty cycles. Analyses of multiple fishing campaigns by Japanese longliners throughout the Central Pacific demonstrated significant depredation mitigation on toothed whale activity primarily false killer whales. Other vessel-based systems have been in use since 2004. The acoustic basis for the mitigation, sonar interference or differential hearing of the signal, is not clear.

Buscaino, Bellante, Buffa, Filiciotto, Maccarrone, Di Stefano, Tranchida & Mazzola (2011) clearly demonstrated how interactive DiD pingers prevented depredation by striped dolphin on squid jig fisheries. The pinger significantly reduced depredation but did not appreciably move the dolphins away any distance from the area of fishing activity.

DDD pingers significantly reduced depredation and gear encirclement of common dolphin in fish trawls in EU waters. Mortality rate reduced from 1 to 0.15 per trawl with pinger deployment, and better if pinger malfunctions were incorporated (Northridge, Kingston, Mackay & Lonergan 2011). Australian fisheries could well reduce dolphin mortality rate in fish trawls and purse seines with appropropriate pingers.

Passive sonar interference

Nishida (2007) outlined developing methods to reduce depredation using a variety of systems using entangling materials around target fish. Few of the plethoras of gear copies since Nishida (2007) have addressed the basis for the interaction systems resulting in costly and unwieldy entangling gear launching systems not well suited to a normal longline setting process of 1 hook per 6 seconds.

Deveau & McPherson (2011) describe a process to maximise the acoustic aspects of passive sonar methods often simply referred to as mechanical systems, despite their detection being by acoustic biosonar. The acoustic backscatter of simple gear components is to maximise sonar interference at minimal cost and logistical requirements for fishing crews.

RECENT AUSTRALIAN FISHERY RESPONSE

Acoustic alarms for dugong

Gulf and East Coast fishery operators determined that dugong moved around nets at night with operating alarms (McPherson, Ballam, Stapley, Peverell, Cato, Gribble, Clague & Lien 2004). Approaching mammals may be alerted to the acoustic signatures of nets, fish in nets or simply fishery operators making alerting sounds. The concept of an acoustic alert process for inattentive dugong or dugong unaware of obstacles in their movement pathway is therefore known to industry. Acoustic alarms/pingers simply provide a more consistent function. The trials on the effectiveness of acoustic pingers on reducing marine mammal interactions with nets were completed in 2004 and were independently assessed through Commonwealth EPBC Act legislation (Assessment of the ecological sustainability of management arrangements for the Gulf of Carpentaria Inshore Finfish Fishery 2004). As entanglements are rare events the conclusions relating to alarms/pingers for dugong were biologically important

The NGNRM dugong/dolphin acoustic alarm developed with NHT2 funding is shown in Figure 3. The alarm was rechargable to suite remote northern Australian waters.

Figure 3. NGNRM dugong alarm casing with 2 sound generating inserts on a charger locally made in the fishery region.

The alarm was established at 3.5 kHz within 1/3 octave of peak of dugong vocalisations established by Ichikawa, Tsutumi, Arai, Akamatsu, Shinke, Hara & Adulyanukosol (2006) to maximise detection capability (Figure 4). The Source Level of the dominant tone is 136 dB re 1 microPascal at 1m over a 0.3 second duration relative to a mean Source Level of dugong calls of 142 dB re 1µPa at 1m (Ichikawa, Akamatsu, Shinke, Adulyanukosol & Arai (2011).

To support the acoustical basis for the selection of acoustic alarm signals Ichikawa, Akamatsu, Shinke, Adulyanukosol & Ara (2011) demonstrated that playback of natural and artificial dugong calls with a range of frequencies between 2 and 5 kHz attracted dugong to an average 20 m of the playback speaker. Playback of 3.5 kHz tones was associated with an average approach distance of around 100 m within an overall detection range extending out to 250 m. Dugongs responded acoustically and behaviourally, differentially to the natural and synthetic dugong calls and acoustic alarm sounds.

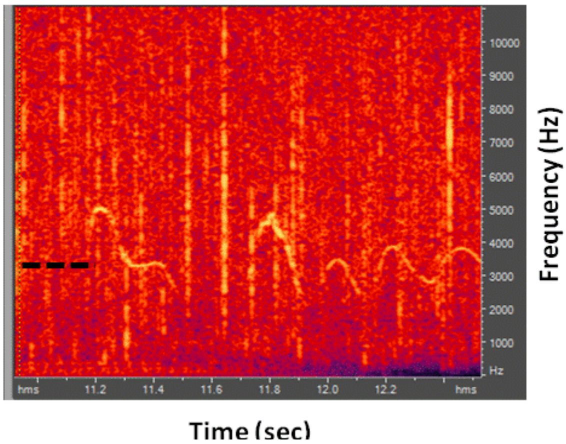

Figure 4. Spectrogram of dugong chirps with background noise from snapping shrimp. The horizontal black line represents the frequency of 3.5 kHz dugong acoustic alarm.

Ichikawa, Akamatsu, Shinke, Adulyanukosol & Arai (2011) determined that the dugongs could localise the 3.5 kHz acoustic alarm equivalent sound, perfect for use as an acoustic alarm. McPherson, Ballam, Stapley, Peverell, Cato, Gribble, Clague & Lien (2004) concluded alarm spacing should be close enough that a sound field on a net should not present any approaching animal with a region of reduced sound suggesting a 'gap' in the sound isopleths between alarms.

The results of Hodgson (2004) and Hodgson, Marsh, Delean & Marcus (2007) recommended that acoustic pingers would not likely reduce bycatch of dugongs. Their assertions were based on observations in clear water in daylight hours when nets are not commercially deployed and local anthropogenic activity was high. An absence of a startle response by the dugongs was interpreted as a 'failure' of the alarms to function as a 'deterrent' to pingers on nets. Hodgson, Marsh, Delean & Marcus (2007) omitted to indicate that the 'simulated net' of Hodgson (2004) was in fact no net at all, just vacant water between two obvious widely spaced operating alarms. Where dugongs chose to move through the 'net' that did not exist the dugong behaviour was advanced as 'evidence' of a failure of acoustic alarms in gillnet fisheries.

Australian fishermen should be aware that recommendations made to fisheries management agencies about pingers not being effective for dugong are based on methods described by Hodgson (2004) (http://eprints.jcu.edu.au/73/ accessed 2/8/2011). The fishing industry should decide themselves if the conclusions expressed to fisheries agencies were representative of commercial fishing operations.

Acoustic alarms and dolphins

McPherson, Ballam, Stapley, Peverell, Cato, Gribble, Clague & Lien (2004) determined that dolphins exhibited aggressive behaviour toward the specific Airmar 10 kHz pingers irrespective if they were on nets with clear video evidence also recorded by Queensland Fisheries Observers. Commercial fishery operators immediately stopped using the Airmar pinger although the Queensland and KwaZulu Natal Sharks Board shark control programmes maintained use of this pinger type with continued dolphin mortality.

The failure of the Airmar pinger to mitigate dolphin entanglement was a failure of the Airmar pinger type with Indo-Pacific bottlenose dolphin only but noted in a fishery context at least. Cox, Read, Swanner, Urian & Waples (2003) observed that entanglement was a rare event compared to the number of interactions between dolphins and gillnets irrespective of whether Dukane 10 kHz pingers were present or not. Read, Waples, Urian & Swanner (2003) concluded that dolphins become entangled when they are unaware of the net, or are distracted by other stimuli in its vicinity. Fishing activities in Queensland are conducted primarily during the hours of darkness when dolphin echolocation (both acoustic power and inter-click intervals) would have been reduced (Goodson, Klinowska & Bloom 1994) especially if no acoustic cues existed around nets.

Soto, Marsh, Noad, Parra & Everingham (2010) considered that Fumunda 10 kHz pingers would not be suitable for Indo-Pacific humpback dolphins in Queensland waters. Their conclusion was based on observations that a) the pingers did not deter or force humpback dolphins away from the constant frequency pingers and b) that the movement of dolphins was not haltered by a "simulated net" that was implied to exist between two isolated pingers anchored on floats. The observations were conducted in daylight in clear waters.

Amir (2010) determined that Fumunda 10 kHz pingers significantly reduced bycatch of Indo Pacific bottlenose dolphins in a commercial fishery in Zanzibar achieving both biological relevance and statistical significance under real world fishery conditions. Biological importance of the pinger type for Indo Pacific humpback dolphin in a commercial fishery context appeared, again bringing into question the relevance of the out of fishery context relevance of the assertions of Soto, Marsh, Noad, Parra & Everingham (2010).

The NGNRM high frequency pinger utilises a signal comparable to that demonstrated by Peddemors, de la Mere & Keith (1999) to reduce bycatch of Indo Pacific humpback dolphin, with higher Source Level and duty cycle more suited to surf zone operation. The fundamental frequency is based on combinations of Frequency Modulated tones 10 to 30 kHz, with significant harmonics extending through 20-60 kHz. Dolphin reaction to the pinger type more like a "stand off behaviour".

DISCUSSION

Commercial fishery operators have the opportunity to decide for themselves how an acoustic approach incorporating acoustic alarms/pingers to bycatch mitigation offers enhanced potential to mitigate acknowledged already low bycatch rates. There are no suggestions that pingers, for example, are perfect and ICES (2011) identified further areas for improvement and cost effectiveness for pingers.

The bycatch mitigation aspects of pingers are relatively understood. The role and opportunity for acoustics with depredation mitigation of toothed whales with fish trawls, gillnets and baited line fisheries is constantly developing (McPherson & Gribble 2011). An acoustic based bycatch mitigation strategy previously funded by NHT1 and NHT2 with alarms designed by JCU Engineering offers a proactive and less damaging alternative (to dugong and dolphins, and to net fishery operators) than current Fisheries policy that requires fishermen to be in attendance with nets to try to release dugongs when they become entangled during night fishing periods.

A 'real-world' commercial net features colour and shape, it would generate sound when anchored in a strong current. Of significance to a dolphin echolocating at night around nets associated with pingers is that the net would feature an echo return from the dolphins own sonar. No such return echo would occur from the "simulated net" as nothing was there to generate a return echo. There would be no reason for a dolphin to not move towards or between the "simulated net" especially as the sound of a nearby pinger clearly had no effect on the dolphins.

Why Hodgson (2004), Hodgson, Marsh, Delean & Marcus (2007) and Soto, Marsh, Noad, Parra & Everingham (2010) failed to use any form of material to link isolated pingers and to refer to the space between as a "simulated net" is not clear. At best their experimental situations could be described as unlike any fishing net situation ever experienced anywhere, and the results would in no way be relevant to fishing operations. Animal Ethics approved 'simulated nets' with visual and sonar responsive attributes have been documented since the early 1990's although 'real world' testing using acoustic localisation around commercial gear is still preferred.

Unfortunately some work, deliberate and accidental, has contributed to the stifling of acoustic mitigation work resulting in the needless mortality of marine mammals. Industry must be prepared to critically examine experimentation, results and conclusions by others that have major impacts on their fishery operation. The literature relating to misinterpretation of data and constrained hypothesis selection to facilitate achievement of a preconceived result is summarised by Martin (1992). Morley, Rosner & Redwood (2001) provided examples of scientific mis-representation that were *intended* to achieve a preconceived result which were often tied to a vested interest, financial or otherwise.

Fishing industries internationally have an expanding range of acoustic options to mitigate marine mammal interactions ranging from long range avoidance to close range mininisation of interactions. ICES (2011) noted for pingers at least that "the market for pingers is currently so limited that commercial research and development has been stifled". The pinger market could well be expanded with subsequent advantages to industry with the incorporation of appropriate acoustic engineering research with fishing industry support.

Monitoring real fishery conditions using Marine Mammal Observer visual techniques is increasingly being shown to be inadequate relative to acoustic methodologies, especially for the hours of darkness when most fishing occurs. Incorporation of acoustic monitoring into marine mammal interaction fisheries as is the case internationally would expedite the capability of industry to defend its activities from inappropriate criticism, erroneous advice to fisheries regulatory agencies and to achieve appropriate biodiversity targets.

REFERENCES

Alfaro-Shigueto, J 2010, Experimental trial of acoustic alarms to reduce small cetacean by catch by gillnets in Peru Final Report to Rufford Small Grants Foundation February 2010 14p. http://www.ruffordsmallgrants.org/files/SM_Joanna%20Alfaro%20Detailed%20Final%20Report.pdf.

Amir, O 2010, Biology, ecology and anthropogenic threats of Indo-Pacific bottlenose dolphins in east Africa. PhD Thesis, University of Sweden.

Assessment of the ecological sustainability of management arrangements for the Gulf of Carpentaria Inshore Finfish Fishery, 2004, Department of Environment & Heritage. Canberra. ISBN: 0 642 55068 9.

Bache, SJ 2003, Bycatch mitigation tools: selecting fisheries, setting limits, and modifying gear. *Ocean and Coastal Management,* vol.46, pp. 103–125.

Barlow, J & Cameron, GA 2003, Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. *Marine Mammal Science,* vol. 19, no. 2, pp. 265-283.

Brotons, JM, Munilla, Z, Grau, AM & Rendell, L 2008, Do pingers reduce interactions between bottlenose dolphins and nets around the Balearic Islands?. *Endangered Species Research,* vol. 5, pp. 1-8.

Buscaino, G, Buffa, G, Sara`, G, Bellante, A, Tonello, AJ Jr, Sliva Hardt, FA Cremer, MJ, Bonanno, A, Cuttitta, A & Mazzola, S 2009, Pinger affects fish catch efficiency and damage to bottom gill nets related to bottlenose dolphins. *Fisheries Science,* vol. 75, pp. 537–544.

Buscaino, G, Bellante, A, Buffa, G, Filiciotto, F, Maccarrone,V. Di Stefano, V, Tranchida, G & Mazzola, S 2011, Depredation of striped dolphin on squid fishery and behavioural responses to interactive pinger. *Journal of the Acoustical Society of America,* vol. 129, no. 4, pp 2399.

Cox, TM, Read, AJ, Swanner, D, Urian, K & Waples, D 2003, Behavioral responses of bottlenose dolphins, Tursiops truncatus, to gillnets and acoustic alarms. *Biological Conservation,* vol. 115; pp. 203–212.

Deveau, D & McPherson, G 2011, Application of passive acoustic reflectors to mitigate toothed whale depredation on longlines, *Journal of the Acoustical Society of America,* vol. 129, no. 4, pp. 2399.

Erbe, C, McPherson, G. & Craven, A. (2011). *Acoustic Investigation of Bycatch Mitigation Pingers,* Project Report 10/21 to Australian Marine Mammal Centre. JASCO Applied Sciences, Brisbane.

Goodson, AD, Klinowska, M & Bloom, PRS 1994, 'Enhancing the acoustic detectability of gillnets', WF Perrin, GP Donovan & J Barlow (eds.), *Gillnets and Cetaceans,* Black Bear Press Cambridge, pp. 585-595.

Harwood, MB, McNamara, KJ, Anderson, GRV & Walter, DG 1984, 'Incidental catch of small cetaceans in a gillnet fishery in northern Australian waters', *Report of the International Whaling Commission,* vol. 34, pp. 555-559.

Hodgson, AJ 2004, Dugong behaviour and responses to human influences. PhD Thesis, James Cook University, Townsville, Queensland, Australia.

Hodgson, AJ; Marsh, H; Delean, S & Marcus, L 2007, Is attempting to change marine mammal behaviour a generic solution to the bycatch problem? A dugong case study. *Animal Conservation,* vol. 10. no. 2, pp. 263-273.

ICES. 2011, Report of the Workshop to Evaluate Aspects of EC Regulation 812/2004 (WKREV812), 28–30 September 2010, Copenhagen, Denmark. ICES CM 2010/ACOM:57.

Ichikawa, K, Tsutumi, C, Arai, N, Akamatsu, T, Shinke, T, Hara, T & Adulyanukosol, K 2006, Dugong (*Dugong dugon*) vocalisation patterns recorded by automatic underwater sound monitoring systems, *Journal of the Acoustical Society of America,* vol. 119, no. 6, pp. 3726-3733.

Ichikawa, K, Akamatsu, T, Shinke, T, Adulyanukosol, K & Arai, N 2011, Callback response of dugongs to conspecific chirp playbacks. *Journal of the Acoustical Society of America,* vol. 129, no. 6, pp. 3623-3629.

Imbert, G & Gaertner JC 2001, Expertise Scientifique de la Thonaille Medterraneenne; Rapport d'etape Suivi Scientifique. Marseille, Centre d'Oceanologie de Marseilles, Universite de la Mediterranee.

Kastelein, R, van der Huel, S, van der Veen, J, Verboom, WC, Jennings, N, der Han, D & Reijnders, PJH 2007, Effects of acoustic alarms, designed to reduce small cetacean bycatch in gillnet fisheries, on the behaviour of North Sea fish species in a large tank. *Marine Environmental Research,* vol. 64, pp. 160-180.

Lien, J, Barney, W, Todd, S, Seton, R & Guzzwell, J 1992, 'Effects of adding sounds to cod traps on the probability of collisions by humpback whales', *Marine Mammal Sensory Systems*, J Thomas, R Kastelein. & AYa Supin (eds), Plenum Press, New York, pp. 701-708.

Leeney, RH, Berrow, S, McGrath, D, Obrien, J, Cosgrove, R & Godley, BJ 2007, Effect of pingers on the behaviour of bottlenose dolphins. *Journal of the Marine Biological Association of United Kingdom,* vol. 87, pp. 129-133.

Martin, B, 1992, Scientific fraud and the power structure of science. *Prometheus*, vol. 10, no. 1, pp. 83-98.

Martı´nez-Abraı´n, A 2008, Statistical significance and biological relevance: A call for a more cautious interpretation of results in ecology. *ACTA Oceologica,* vol. 34, pp. 9-11.

McCauley, R & Cato, D 2003, 'Acoustics of marine mammals: Introduction, impact, threats and potential as a research tool'. *Fisheries, Tourism and Management*, Gales, NJ, Hindell, M & Kirkwood, R (eds) 2003. Marine Mammals and Humans:. CSIRO Press, Melbourne, Australia, pp. 344-345.

McPherson, GR 2010, 'Acoustic pingers to mitigate marine mammal gillnet bycatch - the biosonar basis for their optimum utilization, and approaches for mitigating both bycatch and depredation', *Fifth International Fishers Forum on Marine Spatial Planning and Bycatch Mitigation*, Taipei, August 3-5, 2010. Western Pacific Regional Fishery Management Council & Fisheries Agency, Taiwan.

McPherson, GR, Ballam, D, Stapley, J, Peverell, S, Cato, DH, Gribble, N, Clague, C & Lien, J 2004, Acoustic alarms to reduce marine mammal bycatch from gillnets in Queensland waters: optimising the alarm type and spacing. *Proceedings of ACOUSTICS 2004*, Gold Coast, Australia, 3-5 November 2004, 363-368.

McPherson, GR, Cato, DH & Gribble, NA 1999, '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.

McPherson, GR, Clague, CI, McPherson, CR, Madry, A, Bedwell, I, Turner, P, Cato DH & Kreutz, D 2008, *Reduction of interactions by toothed whales with fishing gear. Phase 1. Development and assessment of depredation mitigation devices around longlines*. Final Report to Fisheries Research and Development Corporation Report Number 2003/016. Department of Primary Industries and Fisheries, Cairns, Queensland, Australia.

McPherson, G, Clarke, G, Hingley, B, McPherson, C & Erbe, C 2011, Development of an acoustic-based toothed whale depredation detection system for longline fisheries. *Journal of the Acoustical Society of America,* vol. 129, no. 4, pp. 2398.

McPherson, G & Gribble, N 2011, Acoustic pingers to mitigate dolphin bycatch and depredation, barely a one third octave between them. *Journal of the Acoustical Society of America,* vol. 129, no. 4, pp. 2399.

McPherson, GR, Lien, J, Gribble, NA & Lane, B 2001, Review of an acoustic alarm strategy to minimise bycatch of humpback whales in Queensland coastal gill net fisheries, Memoirs of the Queensland. Museum, vol. 47, no. 2, pp. 499-506.

McPherson, G & Nishida, T 2010, An overview of toothed whale depredation mitigation efforts in the Indo-Pacific region, *SPC Fisheries Newsletter,* vol. 132, pp. 31-36.

Mooney, TA, Au, WWL, Nachtigall, PE & Trippel, E A 2007, Acoustic and stiffness properties of gillnets as they relate to small cetacean bycatch. *ICES Journal of Marine Science,* vol. 64, pp. 1324–1332.

Morley, J, Rosner, AL & Redwood, D 2001, A case study of misrepresentation of the scientific literature: recent reviews of chiropractic. *Journal of Alternate and Complementary Medicine,* vol. 7, no. 2, 127-128.

Nishida, T 2007, Review of Mitigation methods. Workshop on the depredation in the tuna longline fisheries in the Indian Ocean**.** IOTC-2007-DWS-[A3-01].

Nishida, T & McPherson, G 2011, Assessment of specialized acoustic pingers to mitigate toothed whales depredation on Japanese tuna longline catches in the Central Pacific. *Journal of the Acoustical Society of America,* vol. 129, no. 4, pp. 2399.

Northridge, S, Kingston, A, Mackay, A & Lonergan, M 2011, Bycatch of Vulnerable Species: *Understanding the Process and Mitigating the Impacts.* Final Report to Defra Marine and Fisheries Science Unit, Project no MF1003. University of St Andrews. Defra, London.

Peddemors, VM, de la Mere. S & Keith, M 1999, 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.

Perrin, WF, Donovan, GP & Barlow, J 1994, 'Report of the workshop on mortality of cetaceans in passive fishing nets and traps' *Gillnets and Cetaceans*, WF Perrin, GP Donovan and J Barlow (eds.), Report of the International Whaling Commission Special Issue No.15. Cambridge.

Read, A & Waples, D 2009, *A pilot study to test the efficacy of pingers as a deterrent to bottlenose dolphins in the Spanish mackerel gillnet fishery*. Draft Final Report. Bycatch Reduction of Marine Mammals in Mid-Atlantic Fisheries Project 08-DMM-02 North Carolina Se Grant Programme. 17 March 2009.

Read, AJ, Waples, DM, Urian, KW & Swanner, D 2003, Fine-scale behaviour of bottlenose dolphins around gillnets. *Proc. R. Soc. Lond. B (Suppl.)* 270, S90–S92.

Reeves, RR, Hofman, RJ, Silber, GK & Wilkinson, D 1996, Acoustic deterrence of harmful marine mammal fishery interactions, *Proceedings of the Seattle Workshop. March 1966*, National Marine Fisheries Service and Marine Mammal Commission USA.

Peter, R & Peddemors, V 2006, Responses of Indo-Pacific bottlenose dolphins to active acoustic devices (pingers) deployed on shark nets in South Africa. *Australasian Society for the Study of Animal Behaviour*, 20–23 April 2006, Macquarie University ~ Sydney.

Shapiro, AD, Tougaard, J, Jorgensen, PB, Kyhn, LA, Balle, JD, Bernardez, C, Fjalling, A, Karlsen, J & Wahlberg, M 2009, Transmission loss patterns from acoustic harassment and deterrent devices do not always follow geometrical spreading predictions. *Marine Mammal Science,* vol. 25, no. 1, pp. 53–67.

Soto, AB, Marsh, H, Noad, M, Parra, G & Everingham, Y 2010, Evaluation of the efficiency of implementing bycatch mitigation measures to protect coastal dolphins in Queensland: A quantitative and qualitative analysis. *MTSRF Project Number 1.4.2a. Impacts and Achievements of the MTSRF. Program for the 2010 Annual Conference of the Marine and Tropical Sciences Research Facility (MTSRF).* 18- 20 May 2010 Pullman Reef Hotel & Casino Cairns, North Queensland.

Wynne, B 1996, 'Misunderstood misunderstandings: social identities and public uptake of science', A Irwin & B Wynne (eds), *Misunderstanding science?* Cambridge University Press, Cambridge, pp. 19–46.