REVIEW OF AN ACOUSTIC ALARM STRATEGY TO MINIMISE BYCATCH OF HUMPBACK WHALES IN QUEENSLAND COASTAL GILL NET FISHERIES

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Humpback whales, *Megaptera novaeangliae*, in Queensland coastal waters are at risk of entanglement in a range of fishing gears and obstacles. Since 1991 the Queensland Shark Control Programme of the Queensland Department of Primary Industries has developed an acoustic alarm bycatch reduction strategy. Four acoustic alarm types attached to gillnets have been utilised in an attempt to 'warn' humpback whales of the presence of these man-made obstacles. Another alarm type, under development, has been distributed to commercial fisheries operating in Queensland waters to reduce the risk of humpback whale entanglement in commercial gear. A standard acoustic warning protocol is under development for humpback whales, integrating specific alarm source levels, acoustic propagation and ambient noise levels. How relevant to humpback whales this standard will be is not clear, however it should provide a benchmark against which whale entanglement, or lack of it, may be compared. ☐ *Humpback whale, entanglement, bycatch, acoustic alarms.*

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The Queensland Shark Control Programme (QSCP) of the Queensland Department of Primary Industries (DPI) was initiated because of a series of fatal shark attacks off the Gold Coast, Sunshine Coast and other Queensland beaches in the summers of 1958-1961 (Fig. 1). The QSCP does not provide an impenetrable barrier to sharks, rather a constant fishing pressure with a combination of gillnets and baited lines that operate to reduce shark numbers in the immediate vicinity of major swimming beaches. The 'mixed gear' strategy of nets and drumlines adapts the type of gear to the physical characteristics of the swimming beach and allows for differences in catch selectivity of large individuals from a wide range of shark species. The policy has provided swimmer protection, with the incidental capture of non-target species lower than that resulting from deployment of nets alone (Dudley, 1998; Gribble et al., 1998).

Humpback whales, *Megaptera novaeangliae*, of the eastern Australian population pass southeast Queensland during their northward migration to calving areas north of Fraser Island from June-August each year. Some whales move close to Gold and Sunshine Coast beaches, often between the shark nets and the surf zone (Lien et al., 1998). After the breeding season, whales with calves move southwards to summer feeding grounds in the Antarctic, passing southeast Queensland in September-November, again with some whales moving close to shore. QSCP records show eight humpback whales were trapped in nets between 1962-1995 off the Gold and Sunshine Coasts, with five being released and three dead in Gold Coast nets Gribble et al. (1998). No records were kept of humpback whale collisions that did not result in entrapment (Lien et al., 1998).

Lien et al. (1990) used mechanical 'low frequency clangers' (50-1000Hz), mechanical 'low frequency beepers' (3,500Hz) and electronic 'high frequency pingers' (27-50kHz) to reduce bycatch of humpback whales in Newfoundland's cod traps. The low frequency 'clangers' did not significantly reduce the probability of entrapment of humpback whales possibly due to logistic reasons. The 'low frequency beepers' did reduce the probability, while the 'high frequency pingers' did not. Due to the manner in which whales were entrapped when 'high frequency pingers' were used, Lien et al. (1990) believed that these entrapment's occurred as the whales were manoeuvring to avoid a collision. Their suggestion was that the whales detected them too late, either as they were too quiet or were detected at an insensitive part of the whales hearing spectrum.

Lien et al. (1990) concluded that humpback whales were not orienting using visual cues during inshore feeding activities in Newfoundland waters, and it was more likely that acoustical cues were the primary stimuli. The observations that humpback whales could move around and mostly avoid nets at night in extremely low light levels and in turbid water, without producing sounds, suggested that acoustic cues from the net were used.

During late 1991 Lien provided acoustic alarms of a mechanical 'low frequency beeper' type to the QSCP and supervised positioning them on the Gold Coast nets. These alarms were deployed during a 16 week period of the 1992 humpback whale migration season. No whales were caught in nets fitted with the alarms.

A paired comparison study of alternating alarmed and non-alarmed nets was commenced for a 26-week period during the 1993 humpback whale migration season. C-CORE alarms were utilised featuring a broadband signal centred on 4kHz. Towards the end of the experimental period a whale was entrapped in a non-alarmed net. The subsequent public pressure resulted in all Gold Coast nets being fitted with alarms for the remainder of the whale migration season, the change effectively terminating the experimental opportunity to examine the effectiveness of alarms.

Lien et al. (1992) demonstrated that acoustic alarms were successful in reducing humpback whale collisions with cod traps. Given that no dramatic decrease in shark catch occurred during the 1992 and 1993 acoustic experiment periods and that no whales had become entangled in alarmed nets, alarms have been routinely fitted to Gold Coast nets during subsequent whale migration periods.

In 1994 a deliberate interaction was observed between a large humpback whale and an alarmed net off the Gold Coast, with the whale circling for some time before charging the net. Smaller whales including calves had moved away as the large whale approached the net. The material, and particularly the net headropes, stretched out of the water and disintegrated under the force. While this behaviour has not been observed again, there have been three further reports of massive holes appearing in net panels and headropes of other alarmed nets on the Gold Coast and Sunshine Coast.

From 1992-1995 a single live release of a humpback whale from a non-alarmed net (due to short term logistical reasons) was recorded in a database operated by rapid response marine rescue groups (Gribble et al., 1998). Such operations are not included in the QSCP database.

QSCP nets are not the only potential hazard for migrating humpback whales. A gillnet that appeared to be from the Australian southern shark fishery was observed entangled around a northward migrating whale off Sydney in 2000. Entanglements in anchor ropes have been reported by crews of small vessels and spanner crab pot lines have also been observed trailing from humpback whales.

A small offshore shark gillnet fishery operates within Queensland continental shelf waters, often in areas where adult whales and calves have been observed but no entanglements have been reported.

CRITICISM OF THE ACOUSTIC BYCATCH REDUCTION POLICY

The acoustic alarm policy developed by DPI, particularly by QSCP, has been criticised from three major viewpoints.

1) Environmental groups disagreed with the potential environmental effects of the QSCP, and considered that acoustic alarms were superfluous to a shark control operation that should not be in operation. Whatever the final biological results of analyses of the QSCP data, the outcomes will be considered primarily in the light of risk to human life and with regard to Government 'duty-of-care' legal responsibilities (McPherson et al., 1998). However, bycatch minimisation is an integral part of the QSCP strategy (Gribble et al., 1998).

2) The effectiveness of alarms, specifically the acoustic propagation of the alarms in relation to various ambient conditions, is uncertain. There was also concern that the alarms could affect the localised migratory behaviour of humpback whales, namely that alarmed nets offshore from specific headlands may direct close inshore migrating whales toward waters with unfavourable navigation conditions and higher ambient noise levels which may mask the acoustic alarm signals. While most humpback whales appear to ignore alarm signals, some approach the sound source while others withdraw from it (Todd et al., 1992). These concerns were well-founded and DPI expended research effort to assess the acoustic propagation of alarm signals in the main areas where QSCP gear was deployed. These assessments are being extended to other offshore

habitats where gear that poses a potential risk for humpback whale entanglement is deployed.

3) QSCP studies did not demonstrate sufficient statistical rigour to provide clear cut conclusions to assess the effectiveness of alarms. These criticisms were based on a premise that if something could not be demonstrated to be effective with >95% probability then there was no effectiveness and no conclusions should be drawn. The Acoustics Deterrents Workshop hosted by the U.S. National Marine Fisheries Service (Reeves et al., 1996) recognised that rigorous experimental procedures should be incorporated into any fishery study using acoustic alarms. However, the report recognised that some fisheries would never have sufficient fishing power to demonstrate statistically whether acoustic alarms could reduce marine mammal bycatch. Reeves et al. (1996) indicated that experiments that could not provide statistical probabilities beyond the most rigorous standards were still relevant provided the observations were taken in context of other observations that demonstrated the same trend. The report suggested that behavioural studies monitoring responses of mammals to dummy or 'pseudo' nets with active and non-active alarms (Koschinski & Culik, 1996; Stone et al., 1997) could provide larger sample sizes to determine effectiveness of alarms.

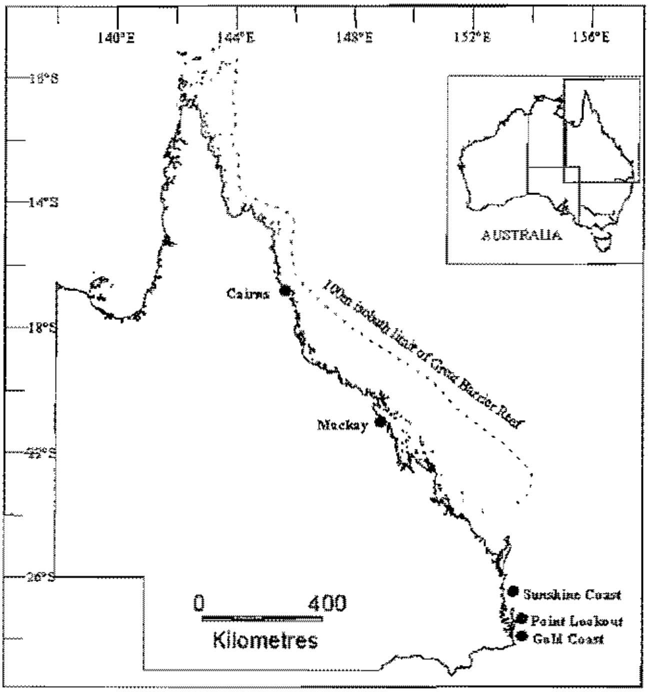

FIG. 1. Map of Queensland showing selected Queensland Shark Control Programme contract locations.

CHANGES IN RISK TO WHALE ENTANGLEMENT SINCE 1991

In 1991 the only gear that appeared to pose a threat to humpback whales in Queensland waters were eleven 186m gillnets anchored off the surf zone on Gold Coast beaches. Since that time Paterson et al. (1994) have reported increases in whale numbers of 11.7% per annum. The observations of Paterson et al. (1994) were conducted off Stradbroke Island immediately north of the Gold Coast. It is not clear what proportion of the humpback whale population observed from Stradbroke Island passed within close proximity of Gold Coast QSCP nets, although it is reasonable to assume that the number passing the Gold Coast has increased in proportion to the population increase.

With the steady increase in numbers humpback whales have appeared in waters where they had not been observed, at least over the past 35-40 years. There is anecdotal information from QSCP contractors (e.g. J. Backmann, pers. comm.) indicating that humpback whales had previously visited those areas, but not since the mid 1960's, prior to when the eastern Australian population was reported to have been at its lowest (Paterson et al., 1994). In 1996 a humpback whale calf was entangled in a QSCP gillnet off the Sunshine Coast (NW of the Gold Coast) during the southward migration and, as a result, was temporarily beached in the surf zone. In 1997 near entanglements occurred off the harbour mouth at Mackay (Fig. 1). Acoustic alarms have now been attached to QSCP gillnets at Mackay (5) and Sunshine Coast (11).

FIELD AND ANALYTICAL METHODS

Acoustic signals from alarms were recorded with a GEC-Marconi SH101X calibrated 100kHz hydrophone, a low noise Royal Australian Navy Research Laboratory pre-amplifier and a Sony TCD-D8 DAT recorder. The system had a frequency response of 15-22,000Hz. Tapes were

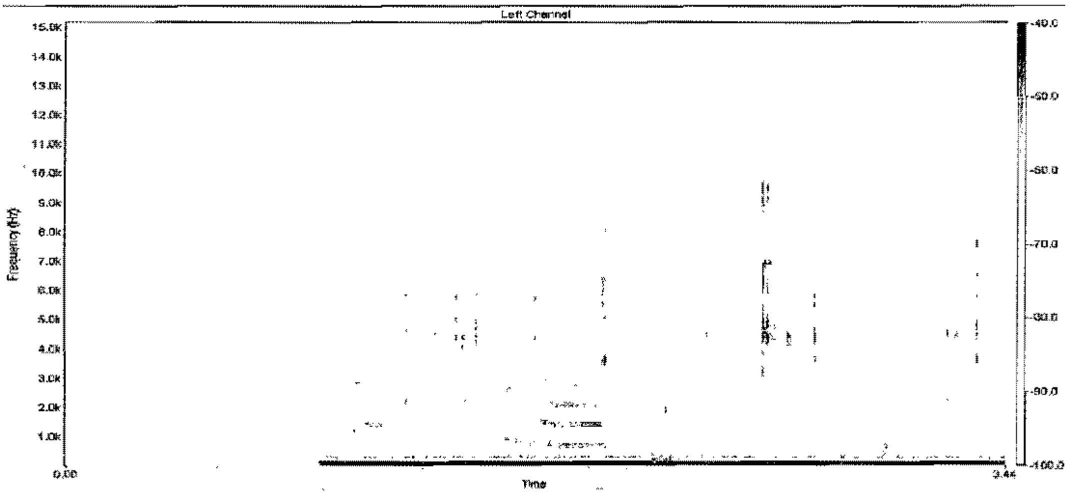

FIG. 2. Spectrogram of repeated signals from at least six C-CORE mechanical alarms (vertical broadband signals between 2-12kHz), three Dukane 'Netmark' alarms (horizontal tone burst at around 11 kHz) and humpback song components off the Gold Coast. C-CORE and Dukane alarms were on a net 100m from the hydrophone, and possibly another further away. Location of the calling whale was not known.

analysed using 'Spectra Plus' acoustics software with an AWE-64 sound card at a sampling rate of 44,100Hz, with a Fast Fourier Transform (FFT) of 1,024 points and a filter bandwidth (FFT bin width) of 43.07Hz. When measuring the levels of the fundamental frequencies of the alarms, no correction was made for the filter bandwidth because of the sinusoidal character of the signals. Sound pressure levels (SPL) were expressed as dB re 1µPa. The analysis system was calibrated with a Tektronix TDS-210 digital oscilloscope with an FFT spectrum analyser module.

Background noise spectrum levels (in 1Hz bands) were calculated from the FFT results by correcting for the filter bandwidth from the level in the FFT bin (values given are in dB re $1\mu Pa^2/Hz$). One-third octave bandwidth levels were estimated by adding the bandwidth correction for the 2,810-3,540Hz 1/3 octave band to the spectrum level.

ACOUSTIC ALARM VARIATIONS

Since 1991 four acoustic alarms types have been used to 'warn' humpback whales of the presence of QSCP gillnets. Original alarm deployments were courtesy of Jon Lien who provided mechanical type alarms centred around a fundamental frequency of 4.0kHz that had been used effectively to enhance the acoustic signature of cod traps (Lien et al., 1992). Source levels were up to 145dB re 1µPa at 1metre. These had shown to draw the attention of whales to the sound source, which upon closer inspection was avoided along with the gillnet to which it was attached.

Corrosion and damage incurred by net hauling operations rapidly reduced the number of working alarms. These were replaced during the 1994-1996 migrations by 'C-CORE' alarms (Centre for Cold Ocean Research Engineering, Memorial University of Newfoundland, Canada). The acoustic signature of these mechanical alarms featured a broadband range from 2~12kHz. A spectrogram of C-CORE alarms and 'Dukane' high frequency alarms (Dukane Corporation, Seacom Division, IL, USA) is given in Fig. 2. As some acoustic energy occurred <2.0kHz, which approaches the known audible capacity of most shark species investigated (Corwin, 1981), there was concern that sharks, the target species of the gear, would detect the acoustic signal. Given the short duration that the alarms were deployed on QSCP gillnets, no consistent trend in shark catch was detected. Concerns were also expressed that the electromagnetic nature of the C-CORE alarm signal may affect catches although no data are available on this aspect of performance.

On Lien's second visit to Queensland he supervised the development of a piezo buzzer type alarm, similar to his earlier design and described by Lien et al. (1995). At that time the 50mm diameter plastic sewer pipe and appropriate end caps and threaded fittings used in Canada and USA were not available in Cairns, Australia. The nearest equivalent pipe was 100mm diameter. To minimise damage due to water intrusion, the piezo buzzer (a truck reversing alarm with a fundamental frequency centred around 2.9-3.0kHz) was set in resin in the base of the unit with only the terminals exposed. Acoustic output of the alarms were not as high (source levels ~125-130dB re 1μPa at 1m) as the original alarm described by Lien et al. (1995). The new alarm was ~3 times heavier due to the volume of materials used and trials indicated that alarm source levels declined as alarm weight increased. In many alarms the sound pressure level of the second harmonic frequency was higher than the fundamental frequency. Nonetheless, this inexpensive alarm (~AUD$20), was utilised during the 1997-1998 humpback whale migration seasons with no entanglements on alarmed nets resulting.

Overall size of these 100mm diameter alarms introduced a range of logistical problems associated with deployment on gillnets which resulted in a substantial loss rate from the gear. The QSCP called for expressions of interest for the construction of a replacement alarm and a tender for supply was let to BASA Technical Services (BASA Technical Services, Brisbane, Australia). BASA produced a piezo buzzer alarm with a fundamental output at ~3.4kHz. The alarm was relatively small and used four 1.5V batteries which proved to be light and cost effective. The spectrum is given in Fig. 3; source level exceeded 140dB re 1μPa at 1m. Longevity of the signal has yet to be determined although it is anticipated to be ~21 days continuous operation.

McPherson et al. (1999) described the acoustic features and construction of the Lien (Cairns) piezo alarm, a development of the original piezo alarm described by Lien et al. (1995). Further work has increased the longevity of these alarms to 40 days continuous operation and the alarm is seen as a cheaper variation suitable for deployment within Queensland commercial fisheries, at least until a full production commercial model is available. Environment Australia has funded DPI to continue development and construction of this alarm type for immediate use within commercial fisheries that may take marine mammals. One hundred alarms have been constructed with a number having been provided to gillnet operators to conduct logistical gear deployment trials including attachment to nets, operating depth and vessel storage.

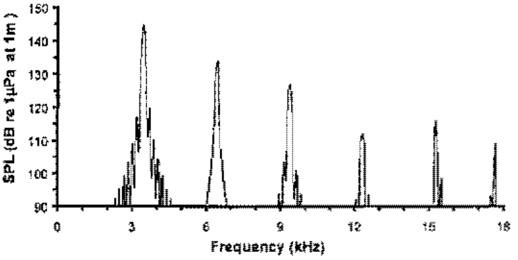

FIG. 3. Spectrum of BASA Technical Services 'whale' alarm.

CURRENT STATUS OF ACOUSTIC ALARM STRATEGY

Research is continuing on the acoustic propagation of alarm signals of the lower frequency alarms (~3kHz fundamental frequency, considered to be most effective for humpback whales) within different environments. QSCP areas include close proximity to high wave energy sand beaches in 5-10m water off the Gold and Sunshine Coasts, and both deeper and shallower waters with more mud bottoms in northern waters. Commercial fishery areas include shallow nearshore environments to more offshore waters between the coast and Queensland's coral reefs in 20-30m.

Alarm performance attributes such as source levels, total acoustic intensity of short tone bursts relative to ambient sound levels, and alarm longevity are being developed and assessed. Until the BASA and Lien (Cairns) alarms currently in use have attained their full development potential, specific recommendations on alarm deployment on obstacles in Queensland waters cannot be made.

The threshold for auditory detection of a signal is considered to occur when the signal level equals the background noise level in a certain bandwidth, known as the masking band (Richardson et al., 1995). Noise outside this band would have little effect on the detection of signals. Research on hearing in marine mammals has shown that a range of values for the width of the masking band exists for tonal signals. Most results vary between 1/6 and 1/3 of an octave, although some are less (Richardson et al., 1995); the most conservative approach is to assume a masking band of 1/3 octave. As the fundamental frequency of the present BASA whale alarms and Lien (Cairns) alarms fall within the 1/3 octave band of 2,810-3,540Hz, the signal-noise-ratio

(SNR) of alarm tone bursts are compared to the background noise within this 1/3 octave band.

Background ambient noise levels include biological noise such as snapping shrimp, wave motion and breaking surf within 20-80m from the nets, depending on tide state. Considerable variability has been detected between different beaches within QSCP contract areas. Ambient levels may change with sea state and wind strength, while at more sheltered beaches ambient noise may be dominated by snapping shrimp with spectral levels between 65-80dB re $1\mu Pa^2/Hz$ at 3kHz irrespective of weather conditions. Ambient levels in fishing areas inside the Great Barrier Reef where water depth is >20m appear to be dominated by fish choruses that may reach spectral levels of 65dB re $1\mu Pa^2/Hz$ at ~3kHz (R. McCauley, pers. comm.).

There are few biological data to determine the most appropriate positioning of alarms on nets in relation to auditory capacity of marine mammals and background noise. Kraus et al. (1995) spaced 10kHz alarms at distances where SPL's had dropped to a SNR of +15dB and demonstrated a significant reduction in bycatch of harbour porpoise. Gearin et al. (1999) placed alarms a distance apart that permitted harbour porpoise to hear 3kHz alarms at a SNR of +10dB up to a Beaufort sea state of 4 (i.e. 11-16 knots).

As spacing between alarms increases it heightens the chance of an acoustic 'hole' occurring for an animal approaching a point on the net, or gear, midway between two alarms. The only discernible acoustic cues would be on either side of the approaching animal, but not directly ahead. Acoustic 'holes' would be more significant where the range from the line of sources is less than the source spacing, which would normally be the case of interest. In this situation, the received signal would be dominated by the contributions of the closest two alarms, and the contributions from other alarms could be neglected. The received signal is lowest when the receiver (animal) is on a line which crosses the line of alarms at right angles and mid-way between two adjacent alarms.

The minimum distance from the net that provides humpback whales sufficient time or space to avoid a collision was considered to be 15m based on the maximum length for the species. Lien et al. (1990) and Lien et al. (1992) indicated that the circumstances in which humpback whales were caught in both alarmed and non-alarmed nets suggested that in some instances the whales were attempting to avoid the gear, but probably detected it too late to avoid collision. No SNR data were available for these experiments.

For a particular background noise level, the spacing of alarms required to give a minimum SNR of a chosen value of +10dB (or the more conservative +15dB) within 15m of the net can be determined using the method given by McPherson et al. (1999). Assessment of alarm signal propagation and ambient noise levels is conducted for each beach within QSCP contract areas, or commercial fishery areas. Under most alarm, propagation and ambient level conditions, a +15dB SNR is achieved 15m out from each net between adjacent alarms, if alarms are spaced 50m along the net. As QSCP nets are 186m in length, contractors are currently required to position five alarms on gillnets a minimum of 45m apart, to achieve this SNR/distance out scenario.

Whether the +15dB SNR at 15m from the net scenario is appropriate is not known, however it is a minimum or known acoustic standard against which whale entrapments, or lack of them, can be compared.

FUTURE RESEARCH

Environment Australia has funded DPI, University of Queensland, Memorial University of Newfoundland, SEANET and Queensland Parks and Wildlife Service to examine the behavioural responses of dugongs and dolphins to acoustic alarms. Funding has also been provided for the further development of the Lien (Cairns) alarm for deployment throughout Queensland's gillnet fisheries, including those that may interact with humpback whales. It is hoped through these experiments we will come to more fully assess bycatch in gillnet fisheries and develop effective means to minimise it.

DPI does not believe it would be appropriate to conduct acoustic alarm research that may jeopardise the lives of marine mammals simply in order to achieve more rigorous experiments that would demonstrate >95% probability of effectiveness for alarms. Gribble et al. (1998) described the level of bycatch of marine mammals in Queensland gillnet fisheries as probably minor and there will be no attempt to raise fishing effort to increase bycatch numbers simply to achieve a statistical probability.

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