Australian Government

Australian Fisheries Management Authority

Mitigation of marine mammal bycatch in gillnet fisheries using acoustic devices - literature review.

SARDI

SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

fishwell CONSULTING

A.I. Mackay and I.A. Knuckey

December 2013

Mitigation of marine mammal bycatch in gillnet fisheries using acoustic devices, literature review.

A.I. Mackay and I.A. Knuckey

December 2013

This publication may be cited as:
Mackay, A.I.[1] Knuckey, I.A[2] (2013). Mitigation of marine mammal bycatch in gillnet fisheries using acoustic devices - literature review. Final Report to the Australian Fisheries Management Authority. 25pp.

[1] **South Australian Research and Development Institute (SARDI)**
SARDI Aquatic Sciences
2 Hamra Avenue West Beach SA 5024
Telephone: (08) 8207 5400
http://www.sardi.sa.gov.au

[2] **Fishwell Consulting Pty Ltd**
27 Hesse Street, Queenscliff, VIC, 3225
Telephone: (03) 5258 4399
http://www.fishwell.com.au

Cover photograph: FV Lutarna – SESSF shark gillnet vessel
owned by Southern Sea Eagles Pty Ltd

This project is supported by the Australian Fisheries Management Authority, through funding from the Australian Government's Caring for our Country

CARING FOR OUR COUNTRY

TABLE OF CONTENTS

EXECUTIVE SUMMARY

During 2011, numerous interactions with dolphins were reported off South Australia in shark gillnets operating under the Gillnet Hook and Trap Fishery (GHAT) sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF). The majority of bycaught dolphins were identified as common dolphins (*Delphinus delphis*), but some were identified as bottlenose dolphins (*Tursiops* sp.). In response, the Australian Fisheries Management Authority (AFMA) closed an area identified to have high dolphin bycatch rates and is currently developing a Dolphin Management Strategy which will be implemented in 2014 to reduce interactions with dolphins in the GHAT fishery. The strategy will involve each boat in the fishery being individually responsible for minimising interactions with dolphins and remaining below a threshold interaction rate. Management responses will focus on operators who have interactions, providing more incentives for those individuals to change their fishing behaviour and use mitigation strategies best suited to their circumstances and location. AFMA commissioned the current study to review acoustic mitigation of marine mammal bycatch in gillnet fisheries, present effective options for fishers to minimise interactions with dolphins, and consider practical applications and other issues such as the “dinner bell” effect for pinnipeds.

Acoustic mitigation devices or “pingers” are used, or have been trialled, in a number of gillnet fisheries to reduce the bycatch of small cetaceans and/or reduce depredation rates of dolphins (usually bottlenose dolphin species).

Controlled experimental trials of pingers have significantly reduced the bycatch rates of harbour porpoises (*Phocoena phocoena*), franciscana dolphins (*Pontoporia blainvillei*), common dolphins (*Delphinus delphis*) and beaked whales (*Ziphius* and *Mesoplodon* sp.). Long-term deployment of pingers in commercial fisheries has shown a continued reduction in bycatch rates of harbour porpoises in bottom set gillnets, and for common dolphins and beaked whale species in a drift gillnet fishery. However, the level of bycatch reduction seen in long-term fishery use is of an order of magnitude lower than reported from controlled experimental trials. This apparent reduced mitigation effect is likely due to a number of factors, most notably lack of compliance and issues with pinger functionality.

Common dolphin bycatch rates have been successfully reduced in drift gillnets equipped with pingers, but as yet, there are no results from pinger trials with bottom set gillnets. While the use of pingers has been successful in reducing the bycatch rate of beaked whales to zero, for other species, bycatch reductions are in the range of 50-90%.

Bottlenose dolphins are commonly reported to depredate gillnets, especially in areas like the Mediterranean Sea (e.g. Brotons *et al.* 2008a), and pinger trials involving gillnets and bottlenose dolphins have focused on mitigating this depredation. While depredation and net damage rates have been reduced, it is clear from behavioural observations that pingers do not keep bottlenose dolphins away from nets. Indeed, bottlenose dolphin species have been caught near functioning pingers (Northridge *et al.* 2003) and have been seen to act aggressively towards them (McPherson *et al.* 2004).

Concerns exist that pingers may result in a “dinner-bell” effect for pinnipeds, i.e. that a conditioned response from the association of the sound produced by a pinger with a beneficial food source will result in increased interactions with fishing gear. A significant increase in sea lion depredation of bottom set gillnets equipped with pingers, compared to those without pingers was reported from a trial in an artisanal gillnet fishery in Argentina (Bordino *et al.* 2002), but not in a subsequent trial testing a pinger with different sound characteristics (Bordino *et al.* 2004). Increased bycatch rates of California sea lions (*Zalophus californianus*) in nets equipped with pingers have been observed in the California-Oregon drift-net fishery (Carretta and Barlow 2011), but the authors attributed this to changes in target catch rates, and a growing sea lion population. Depredation rates in nets with and without pingers were almost equal.

Whether a particular pinger will be affective at reducing marine mammal interactions with fisheries, and in particular reduce bycatch rates, will be species, context and fishery specific.

As there is no data on common dolphin interactions being reduced with pinger equipped bottom set gillnets, it is difficult to recommend particular acoustic mitigation candidates for use in the shark gillnet sector of the GHAT. To be most effective at deterring dolphins, pingers frequency should be in the range of 40 to 110 kHz, but not produce frequencies below 32 kHz, thereby reducing the chance of a dinner bell effect for sea lions.

1. INTRODUCTION

This review was funded by the Australian Fisheries Management Authority (AFMA), to provide a review of available literature on the use of acoustic devices to mitigate bycatch of marine mammals in gillnet fisheries, with particular focus on mitigation of common dolphin and bottlenose dolphin bycatch in demersal gillnet fisheries.

Between September 2010 and September 2011, 52 interactions with dolphins, resulting in 50 mortalities, were reported in the gillnet sector of the Gillnet Hook and Trap (GHAT) sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF), predominantly in Commonwealth waters off South Australia (AFMA 2013). The gillnet sector of the fishery predominantly targets shark species and operates in Commonwealth waters adjacent to South Australia, Victoria and Tasmania.

Independent analysis of camera footage from electronic monitoring (facilitated by AFMA) has been undertaken to identify which species of dolphins have been bycaught in the fishery. A total of 38 of the 40 bycaught dolphins were identified as common dolphins (*Delphinus delphis*), with the remaining two identified as bottlenose dolphins (*Tursiops* sp.). Data on the distribution, population size and genetic structuring of dolphin species in South Australian waters is limited.

In response to these bycatches, AMFA closed an area identified to have high interaction rates between dolphins and gillnet fishing. This “Dolphin Gillnet Closure” has been in place since September 2011 (www.afma.gov.au). Additional gillnet closures exist under the Australian Sea Lion Management Strategy (2010), which was developed to monitor and reduce bycatch rates of threatened Australian sea lions (*Neophoca cinerea*) in gillnets in the GHAT sector of the SESSF. The management strategy includes closures around Australian sea lion colonies and further closures if a pre-specified bycatch limit is reached within a “trigger” zone. 100% observer coverage (either by an independent onboard observer or electronic monitoring) is also required if fishing in the Australian Sea Lion Management Zone, with particular focus on the gear type used in the Gillnet sector of the Gillnet, Hook and Trap Fishery and the marine mammal species interacting with this fishery.

AFMA is currently developing a Dolphin Management Strategy which will be implemented in 2014 to reduce interactions with dolphins in the GHAT sector of the SESSF. A proposed measure is that entry into the current dolphin gillnet closure area will be subject to precautionary eligibility criteria such as having “effective mitigation measures in place”.

1.1. Objectives of the literature review

- Provide a review of acoustic mitigation of marine mammal bycatch in gillnet fisheries
- Present acoustic mitigation options available and relative effectiveness at minimizing interactions with dolphins and potential effects on sea lions, and provide advice on:

  a) the best acoustic mitigation candidate types / model for the likely species (for South Australia, common and bottlenose dolphins) and the type of fishery (demersal bottom set gillnets operating at depths of 50-200m);

  b) other relevant considerations with acoustic mitigation, e.g. underwater noise pollution, risks of dinner bell effect for pinnipeds and practical operational considerations.

2. OVERVIEW OF MARINE MAMMAL GILLNET INTERACTIONS

Bycatch is considered "the greatest immediate and well-documented threat to the survival of cetacean species and populations globally" (Reeves *et al.* 2005). Over 300,000 cetacean fishing related mortalities occur globally on an annual basis (Read *et al.* 2006), with most of these mortalities occurring in gillnets.

One of the greatest challenges faced by managers, fishermen and scientists when trying to find solutions to marine mammal bycatch, is that entanglement events are generally rare, and as a result data relating to such incidents are sparse (Werner *et al.* 2006). Hall (1996) categorised bycatch events based on eight criteria: the spatial pattern; temporal stratification; degree of predictability; whether or not the fishery can control the bycatch event; the type and level of impact; the associated economic and legal implications and the ecological origin of the bycatch. Such categorisation allows specific factors that singularly or collectively influence the occurrence of bycatch to be identified and therefore provides insight into the best approaches to mitigate such events (Hall 1996).

A number of bycatch mitigation strategies have been developed and these can be viewed as following a risk management framework, where the aim of the strategy is either to reduce the risk of exposure of cetaceans to fishing gear or to alter their response to fishing gear when they come in contact with it (Harwood 1999). Examples of such strategies include area restrictions, changes to fishing practices and fishing gear and the use of mitigation measures.

However, for any of these strategies to be implemented successfully, there needs to be sufficient information on bycatch rates within a given fishery and data relating to both the

spatial and temporal occurrence of these events, and their relationship with fishing practices or specific gear characteristics. In gillnet fisheries, strategies that have been investigated to reduce cetacean bycatch rates include time-area closures (Murray *et al.* 2000), gear modifications (Bordino *et al.* 2013) and the use of acoustic mitigation devices or pingers (e.g. Kraus *et al.* 1997). This report will focus on reviewing the available information on the use of acoustic devices to mitigate marine mammal interactions with gillnet fisheries.

3. LITERATURE REVIEW

3.1. Acoustic Mitigation Devices – basic types and terms

Acoustic mitigation devices (AMD) have generally been grouped into two basic categories; Acoustic Deterrent Devices (ADDs) and Acoustic Harassment Devices (AHDs). ADD, commonly referred to as “pingers”, were initially developed to reduce cetacean bycatch by “deterring” them from approaching fishing gear, and are characterised as having a relatively low output source level (<160 dB re1µPa @ 1 metre) and, depending on the model, operate in the 10-100 kHz frequency range containing harmonics in excess of 100 kHz (Dawson *et al*. 2013).

Acoustic Harassment Devices, commonly referred to as “seal scarers”, were initially developed to reduce depredation by pinnipeds, primarily around aquaculture pens, by producing a sound that is loud enough to be aversive to the animal (Götz and Janik 2013). To illicit this response, AHDs in general are much louder than ADDs (>185 dB re 1µPa @ 1 metre) and operate mainly in the 20-30 kHz frequency range, which is the peak hearing range of pinnipeds (Götz and Janik 2013).

More recently, louder ADDs have been developed in order to mitigate cetacean depredation in fisheries, and these devices now produce source levels closer to those of traditional AHDs (Dawson *et al*. 2013).

For the purposes of this review, the term **pinger** will be used to describe acoustic mitigation devices aimed at *reducing fisheries bycatch or depredation*, but excluding seal scarers or other commercial aquaculture acoustic devices.

Pingers have been widely tested as a means of reducing cetacean bycatch and depredation in fisheries. For most marine mammals, and particularly cetaceans, sound is a primary sensory cue used for locating prey, navigation, communication and identifying conspecifics. There are four general hypotheses as to why cetaceans become incidentally

caught in gillnets. These are that they a) are unable to detect nets; b) can detect them but not in time to avoid them; c) can detect them but do not perceive them as a threat; or d) can detect them but get distracted when in pursuit of prey.

Pingers were therefore developed based on the principle that using an acoustic stimulus would modify the behaviour of a cetacean in the vicinity of fishing activities by: a) being aversive to the animals thereby keeping them away from fishing gear; b) encouraging echolocation and thereby increasing the likelihood of detecting the fishing gear; or c) that cetaceans would learn to associate the sound with the presence of nets and therefore perceive this noise as indicating danger (Kastelein *et al.* 1995).

Whether a particular pinger will be effective at reducing marine mammal interactions with fisheries, and in particular reduce bycatch rates, will be species, context and fishery specific.

There are a number of *commercially available* pinger types that have been developed to reduce cetacean bycatch and/or depredation in gillnet fisheries. The acoustic signals produced by these pingers vary in frequency, source level, duration and repetition rate between different commercial brands. Appendix 1 - Table 1 provides a summary of pingers which have been tested in *controlled* experiments in gillnet fisheries and shown to reduce interaction rates with cetacean species. Websites for all pinger models in the table which are currently commercially available are provided in Appendix 2.

3.2. Controlled experiments in gillnet fisheries

In order to assess the mitigation effect of acoustic devices on cetacean bycatch in commercial gillnet fisheries, controlled pinger trials are conducted, allowing bycatch rates to be compared directly between gillnets equipped with pingers and those without (controls).

The first widespread experiment using pingers in a commercial fishery was conducted in the Gulf of Maine set gillnet mixed fishery in the mid-1990s, where a 92% reduction in harbour porpoise bycatch was recorded (Kraus *et al.* 1997). Since then, additional pinger trials in commercial gillnet (fixed and drift) fisheries have also observed a statistically significant reduction in bycatch rates for a number of cetacean species, including harbour porpoise (Gearin 2000, Gönener and Bilgin 2009, Larsen 1999, Larsen *et al.* 2013, Larsen *et al.* 2002, Northridge *et al.* 2011, Richter *et al.* 1999, SMRU *et al.* 2001, Trippel *et al.* 1999), franciscana dolphins (Bordino *et al.* 2004, Bordino *et al.* 2002), beaked whale species (Carretta *et al.* 2008), short-beaked common dolphins (Barlow and Cameron 2003) and one pinniped species, the California sea lion (Barlow and Cameron 2003).

As a result of the reduction in bycatch rates of marine mammals observed in these experiments, pingers have become an integral part of bycatch reduction strategies in the US for the Gulf of Maine set gillnet fishery and the California-Oregon drift gillnet fishery (Carretta and Barlow 2011, Dawson *et al.* 2013, Geijer and Read 2013), and are mandatory for a number of gillnet fisheries in the European Union (ICES 2009). However, effective implementation and compliance rates with regulations in these fisheries are an ongoing issue (see section 2.3).

Cetacean depredation from static gear including gillnets and trammel nets has been recorded in numerous locations around the world (eg. Reeves *et al*. 2001), and measures aimed at stopping depredation have been reported since at least the 18th century (Bearzi 2002). In recent years, new models of pingers have been developed specifically with the aim of reducing marine mammal depredation of fishing gear. These pingers tend to have louder source levels than those traditionally used to mitigate cetacean bycatch in gillnets. The cetacean species most frequently reported to be depredating from gillnets is the bottlenose dolphin (Brotons *et al.* 2008a, Gazo *et al.* 2001, Lauriano and Bruno 2007, Lopez 2006, Pace *et al.* 2003, Rocklin *et al.* 2009). Although interaction rates between bottlenose dolphins and gillnets in some fisheries are frequent, bycatch events are relatively rare (Waples *et al.* 2013). The following section reviews the available information relating to the mitigation of interactions between commercial fisheries and common dolphins, bottlenose dolphins (*Tursiops* sp.) and pinnipeds (with a focus on Australian sea lions).

3.3. Acoustic mitigation devices and common dolphins

To date, one controlled pinger study has reported a significant reduction in common dolphin bycatch rates in a trial in a commercial drift gillnet fishery in the US (Barlow and Cameron 2003, Carretta and Barlow 2011). In addition, a trial in an artisanal commercial drift gillnet fishery in Peru also reported an overall significant reduction in small cetacean bycatch in nets equipped with pingers and a reduction (although not significant) in the bycatch rates of *Deplhinus* spp. (Mangel *et al.* 2013). While an ongoing pinger trial in a commercial bottom set gill and tangle net fishery in the UK has reported a significant reduction in harbour porpoise bycatch rates, sample sizes to date have been too small to determine the effect on common dolphin bycatch rates (Northridge *et al*. 2011). Each of these studies is reviewed in detail below.

Results of a controlled pinger experiment conducted in 1996 and 1997 in the California-Oregon drift gillnet fishery for swordfish and thresher shark showed an 82% reduction in common dolphin bycatch rates in nets equipped with Dukane NetMark 1000 pingers (Barlow

and Cameron 2003). This fishery uses drift gillnets with a total net length of ~1.8 km, with the floatline fished at between 11-22m depth for approximately 12 hours (between dusk and dawn). Stretched mesh sizes range from 35 to 60cm and nets are approximately 49m in height.

Pingers became mandatory in the California-Oregon drift gillnet fishery in 1998, and were required to have the same signal characteristics as those used in the experiment by Barlow and Cameron (2003), i.e. frequency of 10 kHz (±2 kHz) at 132 dB re 1µPa @ 1 metre (±4 dB), duration of 300 milliseconds (±15 milliseconds) and repeated every 4 seconds. The regulations also specify the maximum pinger spacing allowed. In the fishery, pingers are placed on lanyards attached to the floatline and leadline of the net at a maximum spacing of 300 ft (91.44 m). Lanyard length cannot exceed 30 ft (9.14 m) when attached to the floatline and 36 ft (10.97 m) when attached to the leadline. Figure 1 shows the specified configuration of pinger deployment in the fishery (www.nmfs.noaa.gov). The staggered spacing of pingers between the floatline and leadline means that a net of ~1.8km will have 40 pingers attached (Carretta and Barlow 2011).

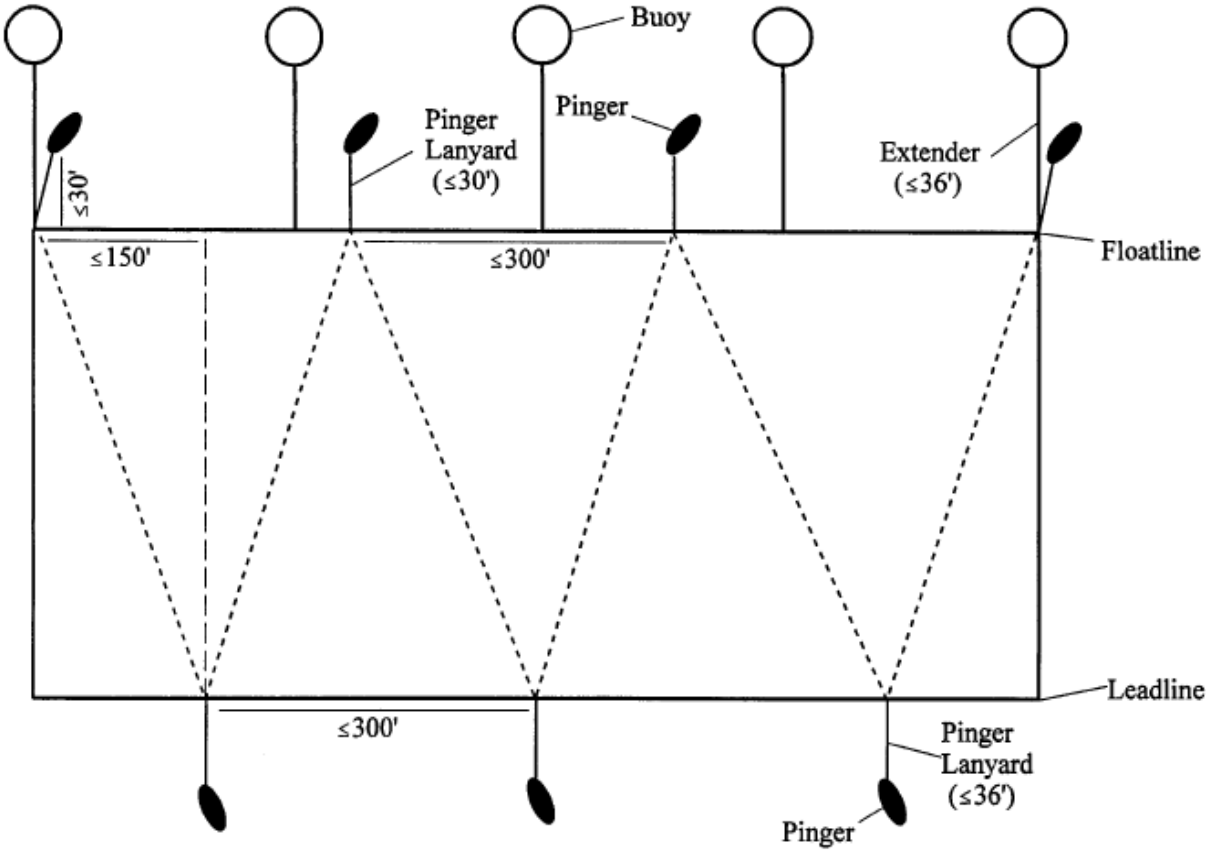

Figure 1: Specified configuration of pinger deployment in the California-Oregon drift gillnet fishery for swordfish and thresher shark. **Taken from US Federal Register, Vol. 64m Bi, 14m January 22, 1999/Rules and Regulations, available at:** http://www.nmfs.noaa.gov/pr/interactions/trt/poctrp.htm

During a trial in an artisanal driftnet fishery for shark and ray in Peru (Mangel *et al.* 2013), common dolphin (*Delphinus* spp.) bycatch rates were found to be reduced by 44%, but this was not significant at the 0.05 level, in nets equipped with pingers (Dukane Netmark 1000). Declines in the bycatch rate of a number of other small cetacean species, including bottlenose dolphins, were also recorded in nets equipped with pingers, however again these declines were not statistically significant. The nets in the fishery use one of three mesh sizes (stretched mesh: 19.1, 20.3, 25.4 cm), are ~ 2 km in length and 14 m high, with the floatline fishing near the surface. Nets are generally fished for 12 hours (dusk to dawn). Pingers were attached on the leadline of the net (therefore at approximately 14m depth). When all small cetacean species were considered, bycatch rates in sets using pingers were significantly lower (37.2%) than in sets without pingers. The decline in bycatch rates of common dolphins was not as great as seen during the controlled trial by Barlow and Cameron (2003) using the same type of pinger in the California-Oregon drift net fishery. There are likely a number of reasons for this. First, the study did not follow a strict paired experimental design, and there was some variation in net characteristics and soak times between control and experimental nets which may have confounded results. Second, only a limited number of pingers were available for the trial, therefore pingers were only deployed on the leadline at a spacing of 200 m. While the average number of pingers per net was not reported by the authors, at the reported spacing between 9 and 11 pingers were likely deployed on each ~2 km net, compared to 40 pingers deployed per 1.8 km net in the California-Oregon driftnet fishery.

Common dolphins are bycaught in static gillnet and tangle net fisheries in the UK south west. Pinger use is required on certain vessels (>12 m) in these fisheries under European Union Council Regulation No. 812/2004 (CR812, http://eur-lex.europa.eu). Under this regulation, pingers with one of two signal characteristics can be used, and depending on the pinger type, must be spaced at 100 m or 200 m intervals along the nets. Total net lengths in these fisheries are generally 2-4 km, but can be up to 8 km. Therefore the industry has questioned whether louder pingers than those mandated in the regulation could be used, so that the number of pingers needed per total net length fished could be reduced and operational issues with pinger deployment could be alleviated. A pinger trial is currently ongoing to test the efficacy of a DDD-03L pinger at reducing harbour porpoise and common dolphin bycatch in the fishery (Northridge *et al.* 2011). DDD-03L pingers produce signals between 5-500 kHz, lasting 0.5-9 seconds on a random interval and have a louder source level than the Dukane Netmark 1000 pingers (174 dB v. 132dB re 1µPa @ 1 metre). For some sets, DDD pingers were placed only at the end of fleets of nets that were up to 8 km in length. Results so far show an overall significant reduction in harbour porpoise rates of 66% in nets with DDD pingers deployed. When the analysis was restricted to net lengths of <4

km, the reduction in harbour porpoise bycatch was 95% (Northridge *et al.* 2011). Common dolphin bycatch rates in nets with and without pingers were too low to determine the effect of DDD pingers on bycatch rates (3 in 780 hauls without pingers, 2 in 929 with pingers). However, the two dolphins bycaught in nets equipped with DDD pingers were 1.3 and 2.5 km, respectively, from the closest pinger.

The three studies reviewed above are the only published pinger trials which have been conducted in gillnet fisheries where common dolphin bycatch occurs. However, both the California-Oregon and Peruvian fisheries are drift gillnet fisheries, where nets are fished either at, or <22m below the surface and have relatively short soak times compared to many fisheries (12 hours). The propagation of the sound field generated by pingers will be dependent on factors including the depth of pinger placement, the water depth and habitat morphology (Shapiro *et al.* 2009).

The effects of pingers on common dolphin bycatch rates in bottom-set gillnet fisheries in the UK south-west cannot yet be fully determined given the relatively small number of observed bycatches and variation in the spacing of DDD pingers and lengths of nets so far observed during the ongoing trial by Northridge et al. (2011). A previous study in the south-west UK found that detections of dolphin echolocation clicks (presumed to be common dolphin) were lower in an area around a gillnet when a pinger was deployed (DDD-02F) than when no pinger was deployed (Northridge *et al.* 2008). In a recent study, detection of dolphin echolocation clicks (bottlenose dolphin and/or common dolphins) recorded 150m from a deployed pinger (Banana Pinger) were reduced by 25% during periods when the pinger was on compared to periods when the pinger was off (Crosby et al. 2013). Free-ranging common dolphins have shown different responses when pingers have been placed in the water from a boat during behavioural studies. Common dolphins showed a strong avoidance response when a pinger (DDD-01) was deployed in the water off France (van Marlen 2007), while no obvious behavioural changes were observed in common dolphins exposed to several different pinger signals in studies off the coast of Ireland and Spain (Berrow *et al.* 2008, Sagarminaga *et al.* 2006).

3.4. Acoustic mitigation devices and bottlenose dolphins

A number of studies have tested the efficacy of acoustic mitigation devices at reducing bottlenose dolphin depredation of bottom set gillnets, using a variety of pinger types with a range of frequencies and source levels (both ~ 132dB and >170dB). An assessment of depredation rates during these studies has generally been made by comparing fish catches, fish damage and net damage between control and pingered nets. Several of these studies

have found that the use of pingers has resulted in a decrease in depredation rates, as determined by an increase in fish catch or a decrease in net damage (Brotons *et al.* 2008b, Buscaino *et al.* 2009, Gazo *et al.* 2008, Northridge *et al.* 2003).

Northridge *et al*. (2003) recorded significantly fewer holes (69%) attributed to being caused by dolphin depredation in trammel nets in Greece equipped with Saver pingers (SL 155dB re 1µPa @ 1m, 30-160 kHz) than in nets without pingers. However, one dolphin was caught in a net with an active pinger. Cox *et al.* (2003) found that bottlenose dolphins showed only subtle displacement around Spanish mackerel gillnets (*Scomberomorus maculatus*) in the US when Dukane NetMark 1000 pingers were deployed. Gazo *et al.* (2008) recorded significantly fewer holes (87%) attributed to bottlenose dolphin depredation in trammel nets in the Balearic islands in nets equipped with Aquamark 100 pingers (SL 145dB re 1µPa @ 1m, 20-160kHz) than in nets without pingers. Buscaino *et al* (2008) reported 31% fewer holes and 28% more fish in bottom set gillnets in Sicily equipped with DDD02 pingers (160dB re 1µPa @ 1m, 0.1-200 kHz) than in control nets. Brotons *et al*. (2008) conducted a large scale pinger trial in the Balearic Island artisanal gillnet fishery where they trialled three different devices (Aquatec AQUAmark 210, Dukane Netmark 1000 and SaveWave Dolphinsaver High Impact Black). Interactions between bottlenose dolphins and nets with active pingers were reduced by 49% overall, however differences in interaction rates were only significant when the Aquamark pinger was used.

Behavioural observations of bottlenose dolphins around nets with pingers show that while interaction rates (measured as closest approach distance or time in the area around the net) may be reduced, interactions are not fully eliminated for this species (Brotons *et al.* 2008b, Cox *et al.* 2003, Waples *et al.* 2013), and bycatches of bottlenose dolphins in nets equipped with pingers can still occur (Read and Waples 2010 cited in Dawson *et al.* 2013, McPherson et al. 2004, Northridge *et al.* 2003). In addition, one study noted increased depredation rates in both control and pinger nets over the two month trial period (Northridge *et al.* 2003).

It is not possible to conclude from these studies whether the use of pingers can reduce the risk of entanglement of dolphins actively depredating nets. In addition, some authors have suggested that as bottlenose dolphins use high-intensity, broadband sounds for intra-specific communication, they are likely to find the types of sounds emitted from pingers to be less aversive than species such as the harbour porpoise (Reeves *et al.* 2001).

3.5. Acoustic mitigation devices and Australian sea lions

Few studies have addressed the effect of pingers on pinniped bycatch rates in gillnet fisheries. In general, pinnipeds are assumed to interact with gillnets because they are depredating nets, therefore a common concern is that the use of pingers will elicit a “dinner-bell” effect, where depredating seals will learn to associate the deterring sound of a pinger with a food source, thereby increasing interaction rates (Jefferson and Curry 1996, Mate 1993, Mate and Harvey 1987). However, quantitative evidence of this effect is limited.

A field experiment in an artisanal bottom-set gillnet fishery in Argentina found that depredation of nets by sea lions (*Otaria favescens*) occurred significantly more frequently on nets with Dukane Netmark 1000 pingers than without, and the rate of sea lion depredation on pingered nets increased over the four and a half month study period (Bordino *et al.* 2002). A subsequent controlled experiment in the same fishery using Airmar pingers (132dB re 1μPa @ 1m, 70kHz) found that sea lion depredation rates on pingered and control nets was similar, although the intensity of depredation was significantly lower on nets with pingers (Bordino *et al.* 2004). The authors suggested that the lack of a “dinner-bell” effect recorded in this trial may have been a direct consequence of the frequency of the pinger used, which is above the hearing sensitivities of sea lions (see below).

The initial pinger experiment in the California-Oregon drift gillnet fishery, also using Dukane Netmark 1000 pingers, found a significant reduction in bycatch rates of California sea lions and a marginally significant decrease for northern elephant seals in sets equipped with pingers compared to control sets (Barlow and Cameron 2003). However, since pingers became mandatory in the fishery, California sea lions have been entangled more than observed prior to the start of pinger use in the fishery (2.6% versus 1.6%), although the difference was not statistically significant. In contrast, depredation rates in pingered and un-pingered sets were almost equal. Carretta and Barlow (2011) suggest this higher bycatch rate with pinger use was likely a result of increasing sea lion population numbers and redistribution of fishing effort into areas where sea lions were more abundant. Bycatch rates of the other pinniped species incidentally caught in the fishery (northern elephant seal) were significantly lower after pingers became mandatory in the fishery.

In order to reduce common and bottlenose dolphin bycatch in gillnets in the GHAT sector of the SESSF, while avoiding increasing interaction rates with Australian sea lions, a pinger would ideally be one that operates in the peak frequency range of hearing for the common dolphin and bottlenose dolphin, but is above the hearing threshold of Australian sea lions. Our understanding of the hearing abilities of marine mammals is limited to a few species and from hearing measurements of single, or a few, individuals within those species.

Bottlenose dolphin hearing has been the best studied, with functional hearing between 75 Hz and 150 kHz and best hearing in the range of 40 to 110 kHz (Au 1993). Only one audiogram exists from a common dolphin, which was live stranded (Popov and Klishin 1998), showing functional hearing up to 150 kHz with a minimum hearing threshold between 50-60 kHz. Seals and sea lions can detect sounds between 10 Hz and 32 kHz (Kirkwood and Goldsworthy 2013, Schusterman *et al.* 1972).

If audiograms from California sea lions are taken as a proxy for the hearing abilities of Australian sea lions, then pingers aimed at reducing dolphin interactions in gillnets in the GHAT fishery would optimally not produce frequencies between 10-32 kHz.

3.6. Commonly cited concerns surrounding pinger use

A number of concerns are frequently cited with regards to the widespread use of pingers in commercial fisheries, most notably whether species will be excluded from important habitat and whether habituation, leading to a reduction in efficacy, will occur. Some information leading to these concerns and current consensus is presented below.

Concerns regarding habituation of cetaceans to pingers have been driven by results of behavioural studies of harbour porpoises, which have found that the initial area of displacement that porpoises have shown to active pingers was reduced over time, albeit over relatively short study periods (Carlstrom *et al.* 2009, Cox *et al.* 2001, Koschinski 1997). However, marine mammal bycatch rates in commercial fisheries where pingers have been used over long time periods have not been found to increase. A long term deployment of pingers in the Danish bottom set gillnet fishery did not result in an increase in harbour porpoise bycatch (Vinther and Larsen 2004). In the USA, a study investigating the effect of mandatory pinger use on harbour porpoise bycatch rates found that there was no increase in incidental captures over a period of nine months in areas where pingers were required, and no increase in annual bycatch rates after pinger use became mandatory in the Northeast gillnet fishery (Palka *et al.* 2008). The authors concluded that these results showed no indication that habituation to pingers had occurred in this region. However, they pointed out that the data analysed did not allow a direct investigation of habituation, because pingers were not used continuously in any one area, and porpoises migrated through management areas and therefore may have spent proportions of the year in areas without pingers. Carretta and Barlow (2011) found no significant difference between bycatch rates of cetaceans (including common dolphins) or pinnipeds (including California sea lions) between early (1996-2001) and late (2001-2009) periods of pinger use, and concluded that habituation was not occurring.

An additional concern around pinger use is that, given the displacement zone shown by some species to active pingers, cetaceans may be excluded from favourable habitat if there is widespread use of pingers. A number of studies have been conducted to investigate the behavioural responses of cetaceans to pingers. Unlike trials in commercial fisheries, these studies have used a variety of experimental set ups to compare behaviour between periods with an active pinger and a control (no pinger), by visually tracking animals around the pinger deployment site, monitoring the occurrence of echolocation rates, or recording the behavioural reactions of individuals to deploying a pinger from a boat. While these experiments have shown an exclusion area around active pingers for harbour porpoises (Carlstrom *et al.* 2009, Cox *et al.* 2001, Koschinski 1997), such a clear effect has not been shown for other cetacean species, or results have been ambiguous. There was no significant difference in the closest approach to a net made by bottlenose dolphins between periods when a pinger was active or inactive (Cox *et al.* 2004). Bottlenose dolphins have been reported bycaught in nets with active pingers (Northridge *et al.* 2003, McPherson *et al.* 2004), and in one Australian study, bottlenose dolphins were observed to act aggressively towards pingers (McPherson *et al.* 2004). Only subtle differences in behaviour towards active pingers have been noted for a number of other species including Australian snubfin (*Orcaella heinsohni*) and humpback dolphins (*Sousa chinensis*) (Soto *et al.* 2013), Hector's dolphins (*Cephalorhynchus hectori*) (Stone *et al.* 2000) and tucuxi (*Sotalia fluviatilis*) (Monteiro-Neto *et al.* 2004).

3.7. Bycatch reduction rates in commercial fisheries with long-term pinger deployment

Since 1999, the use of pingers has been mandatory in certain sectors of US Northeast gillnet fisheries as part of a management plan to reduce harbour porpoise bycatch rates (Orphanides and Palka 2013). While harbour porpoise bycatch rates were reduced by 92% in the fishery during an experimental trial (Kraus *et al.* 1997), observed reductions in the fishery since mandatory pinger use have not been as large (about a 60% reduction in bycatch rates between nets with and without pingers). The reason(s) for this difference are likely due to a number of factors, such as changes in the dynamics of the fishery, gear modifications or different gear characteristics, changes in fishing distribution, compliance with using pingers and the required number of pingers and whether or not pingers have been functioning properly. Compliance rates in the US Northeast gillnet fisheries have ranged from 3% to 58% (Palka *et al.* 2008). Palka *et al.* (2008) found that harbour porpoise bycatch rates were much higher in gillnets with an incomplete set of pingers than in nets with the required number of pingers. In addition, the number of pingers which observers reported as

correctly functioning in the fishery has ranged from 38% to 80% of tested pingers (Orphanides and Palka 2013).

In the California-Oregon driftnet fishery, common dolphin bycatch was reduced by 82% in an experimental pinger trial (Barlow and Cameron 2003), but bycatch reduction rates are about 50% since the pingers have become mandatory. Carretta and Barlow (2011) postulate that the reduction in the efficacy of pingers in the fishery could be due to variability in the number of pingers that were functioning, although they were unable to test this, because there was no systematic recording by observers of whether pingers were working or not until 2001. In the California-Oregon driftnet fishery, cetacean bycatch rates were significantly higher in sets with ≥ 1 non-functioning pinger than in sets where all pingers were working (Carretta and Barlow 2011). However, for sets in which cetaceans were taken, bycatch occurred adjacent to a functional pinger in 84% of the 32 bycatch events where the functional status of the nearest pinger was recorded.

3.8. Operational considerations

The results of a number of trials investigating the practical use of pingers in bottom set gillnet and tangle net fisheries have raised concerns over their robustness, the time needed for deployment or removal from gear, fouling of gear, unreliability in source output and failure rates (Anonymous 2003, Cosgrove *et al.* 2005, SMRU *et al.* 2001). Carretta and Barlow (2011) noted that reasons for pinger failure in the California-Oregon drift gillnet fishery included expired batteries, water intrusion and physical damage to the pingers caused during fishing operations (Carretta and Barlow 2011). In bottom set gillnet fisheries, pingers are deployed on the floatline of the net, and therefore need to be able to pass through hauling gear without being damaged, or need to be easily attached and removed from the net during shooting and hauling.

The spacing at which pingers are deployed along a net has been shown to affect the efficacy of reducing bycatch. Initial spacing requirements for the “Dukane” style pinger used in the US northeast gillnet fisheries mandated pingers were deployed every 92m on the net following results of a controlled pinger experiment (Kraus *et al.* 1997). Under the European Union’s Council Regulation No. 812/2004 a maximum spacing of 100m or 200m (depending of the type of pinger used) between pingers is required. Larsen *et al*. (2013) conducted a controlled experiment to assess bycatch reduction rates when pingers (AQUA*mark*100) were deployed at greater intervals than 200m. Harbour porpoise bycatch rates were 80% lower in nets with pingers spaced at 585m and 100% lower at pinger spacings of 455m than in nets with no pingers.

An ongoing trial in the UK has shown an overall reduction in harbour porpoise bycatch rates of 66% when DDD-03 pingers were deployed at wide spacing on nets up to 8 km in length. This reduction was 95% when the comparison was limited to nets <4km of length (Northridge *et al.* 2011).

The correct spacing for pinger deployment will be a function of the sound properties of the pinger and the behavioural response of marine mammals to that pinger. While previous studies and manufacturer recommendations may provide information on which to judge minimum spacing, a quantitative evaluation would be required to ensure maximum bycatch reduction was achieved for each brand of pinger used. As noted by Erbe and McPherson (2012), the level of bycatch reduction a type of pinger will produce, or the behavioural reaction a marine mammal will have to that pinger, will depend on the sound produced by the pinger (e.g. source level, frequency), the way in which the pinger is deployed (e.g. depth), the sound propagation properties of the location (e.g. sediment type) and the variability in animal response, both between species and within different populations of the same species.

3.9. Requirements of pingers to mitigate dolphin bycatch in shark gillnets of the SESSF

Candidate pingers to minimize dolphin bycatch in the gillnet sector of the GHAT would need to:

- Reduce common dolphin and bottlenose dolphin bycatch without increasing Australian sea lion (or other pinniped) bycatch.

Whilst being:

- Practical to deploy and remove from fishing gear, and be durable enough to withstand normal fishing operations.
- And ideally would allow fishermen and observers to easily assess whether the pingers were functioning correctly.

Common dolphin bycatch rates in two drift gillnet fisheries have been reduced by pingers with a source level of 132 dB, broadcasting a continuous signal of 10 kHz for 300ms at a 4 second interval (Carretta and Barlow 2013, Mangel *et al*. 2013). No “dinner-bell” effect for California sea lions was noted from the long-term deployment of these pingers in the California-Oregon drift net fishery (Carretta and Barlow 2013). However, the same type of pinger was found to increase sea lion depredation rates in a bottom set gillnet fishery (Bordino *et al.* 2002), and no difference was noted in the closest approach bottlenose

dolphins made to active pingers although there were significantly fewer groups observed within 100m of the net when the pinger was active (Cox *et al.* 2004).

There are currently no studies which have reported a reduction in common dolphin bycatch in bottom set gillnets via the use of pingers.

While a number of studies have shown that bottlenose dolphin depredation rates are reduced on nets with active pingers (e.g. Brotons *et al.* 2008b), bycatch of bottlenose dolphin in nets with pingers (e.g. Northridge *et al.* 2003), and observed aggression of bottlenose dolphin to pingers in one study (McPherson *et al.* 2004), suggest that pingers are not effective at reducing bottlenose dolphin entanglement risk.

4. CONCLUSION

Given the above information there is no clear candidate pinger that is likely to mitigate dolphin interactions in the GHAT sector of the SESSF. Common dolphin bycatch rates in drift net fisheries has been reduced in nets equipped with Dukane Netmark 1000 pinger. Although these pingers are no longer produced, other pingers with similar acoustic properties are commercially available (see Appendix 1). However, there have been no studies to investigate the effect of pingers with these acoustic properties on common dolphin bycatch rates in bottom-set gillnet fisheries. Common dolphin bycatch rates in an ongoing experimental trial in a bottom-set gillnet fishery the UK are too low to be able to conclude whether DDD-03L pingers are effective for this species.

In general, marine mammal bycatches are statistically “rare” events, making it difficult to draw conclusions on the efficacy of mitigation measures without having controlled trials, and large sample sizes over spatial and temporal scales relevant to the fishery.

In controlled experimental trials in commercial fisheries, pingers have been shown to reduce the bycatch rates of harbour porpoise, common dolphins and franciscana by 80-95%, and of beaked whales by 100%. However, this level of reduction has not been seen in the two commercial fisheries in which pingers are formally required: the US bottom set gillnet fishery and the California-Oregon drift net fishery for swordfish. Long term reductions in bycatch rates of cetaceans in these fisheries have been 60% for harbour porpoises and 50% for common dolphins, respectively. These lower reductions are most likely a result of a number of factors including low compliance, changes in fishing effort and distribution, and pinger failure.

To date, only one trial, which is ongoing, has been conducted to investigate the effect of pingers on common dolphin bycatch rates, and results from this trial are inconclusive. A number of studies have shown that pingers do not reduce bycatch rates of bottlenose dolphins.

A significant increase in depredation rates by South American sea lions of gillnets equipped with pingers was observed during a controlled experimental pinger trial over a four and a half month period. In contrast, increased depredation rates by California sea lions were not associated with long term pinger use in the California-Oregon drift net fishery.

The efficacy of pingers at reducing bycatch is dependent on being correctly deployed and on functioning properly (i.e. emitting sound at the correct source level). Therefore factors regarding durability and how pingers will be deployed on fishing gear need to be considered.

Whether a particular pinger will be effective at reducing marine mammal interactions with fisheries will be species, context and fishery specific.

5. GLOSSARY

dB (decibel): Unit of sound level, a logarithmic measure of sound strength calculated as $20 \log_{10} (P/P_{ref})$, where P is sound pressure and P_{ref} is a reference pressure (e.g., 1µPa)

Source Level: acoustic pressure that would be measured at a standard reference distance (normally dB 1µPa @ 1 metre)

Habituation (behavioural): Gradual waning of behavioural responsiveness over time as animals learn that a repeated or ongoing stimulus lacks significant consequences

6. REFERENCES

AFMA (2013). Managing interactions with dolphins in the Gillnet Hook and Trap sector of the Southern and Eastern Scalefish and Shark Fishery. Regulation Impact Statement. Australian Fisheries Management Authority. 29 pp.

Anonymous (2003). Trial of acoustic deterrents ('porpoise pingers') for prevention of porpoise (Phocoena phocoena) bycatch - Phase 1 - Deployment Trial. Financial Instrument for Fisheries Guidance (FIFG) Project; SeaFish Report No CR201. Sea Fish Industry Authority.

Au, W. W. L. (1993). The sonar of dolphins. In: The sonar of dolphins. Springer-Verlag, NewYork, p. 227pp.

Barlow, J. and Cameron, G. A. (2003). Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. Marine Mammal Science, 19(2): 265-283.

Bearzi, G. (2002). Interactions between cetaceans and fisheries in the Mediterranean Sea. In Cetaceans of the Mediterranean and Black Seas: state of knowledge and conservation strategies. A report to the ACCOBAMS Secretariat, February 2002, Monaco. p. 20.

Berrow, S., Cosgrove, R., Leeney, R.H., O'Brien, J., McGrath, D., Dalgard, J. and Le Gall, Y. (2008). Effect of acoustic deterrents on the behaviour of common dolphins (Delphinus delphis). Journal of Cetacean Research and Management, 10(3): 227-233.

Bordino, P., Kraus, S., Albareda, D. and Baldwin, K. (2004). Acoustic devices help to reduce incidental mortality of of the Franciscana dolphin (*Pontoporia blainvillei*) in coastal gillnets.IWC SC/56/Sm12:1-10 International Whaling Commision Cambridge

Bordino, P., Kraus, S., Albareda, D., Fazio, A., Palmerio, A., Mendez, M. and Botta, S. (2002). Reducing incidental mortality of Franciscana dolphin *Pontoporia blainvillei* with acoustic warning devices attached to fishing nets. Marine Mammal Science, 18(4): 833-842.

Bordino, P., Mackay, A., Werner, T., Northridge, S. and Read, A. (2013). Franciscana bycatch is not reduced by acoustically reflective or physically stiffened gillnets. Endang Species Res, 21:1-12.

Brotons, J. M., Grau, A. M. and Rendell, L. (2008a). Estimating the impact of interactions between bottlenose dolphins and artisanal fisheries around the Balearic Islands. Marine Mammal Science, 24(1): 112-127.

Brotons, J. M., Munilla, Z., Grau, A. M. and Rendell, L. (2008b). Do pingers reduce interactions between bottlenose dolphins and nets around the Balearic Islands. Endang Species Res, 5: 301-308.

Buscaino, G., Buffa, G., Sara, G., Bellante, A., Tonello, A. J., Hardt, F. A. S., Cremer, M. J., Bonanno, A., Cuttitta, A. and Mazzola, S. (2009). Pinger affects fish catch efficiency and damage to bottom gill nets related to bottlenose dolphins. Fisheries Science, 75(3): 537-544.

Carlstrom, J., Berggren, P. and Tregenza, N. J. C. (2009). Spatial and temporal impact of pingers on porpoises. Canadian Journal of Fisheries and Aquatic Sciences, 66(1): 72-82.

Carretta, J. V. and Barlow, J. (2011). Long-Term Effectiveness, Failure Rates, and Dinner Bell Properties of Acoustic Pingers in a Gillnet Fishery. Marine Technology Society Journal, 45(5): 7-19.

Carretta, J. V., Barlow, J. and Enriquez, L. (2008). Acoustic pingers eliminate beaked whale bycatch in a gill net fishery. Marine Mammal Science, 24(4): 956-961.

Cosgrove, R., Browne, D. and Robson, S. (2005). Assessment of Acoustic Deterrent Devices in Irish Gill Net and Tangle Net Fisheries. Bord Iascaigh Mhara. 33 pp.

Cox, T. M., Read, A. J., Solow, A. and Tregenza, N. (2001). Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? Journal of Cetacean Research and Management, 3(1): 81-86.

Cox, T. M., Read, A. J., Swanner, D., Urian, K. and Waples, D. (2003). Behavioral responses of bottlenose dolphins, *Tursiops truncatus*, to gillnets and acoustic alarms. Biological Conservation, 115(2): 203-212.

Crosby, A., Tregenza, N. and Williams, R. (2013). The Banana Pinger Trial: Investigation into the Fishtek Banana Pinger to reduce cetacean bycatch in an inshore set net fishery. Report to the Wildlife Trusts, Cornwall, UK.

Dawson, S., Northridge, S. P., Waples, D. and Read, A. (2013). To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnet fisheries. Endang Species Res, 19:201-221

Gazo, M., Fernandez-Contreras, M. M., Brotons, J. M. and Aguilar, A. (2001). Interactions between bottlenose dolphins and artisanal fisheries in the Balearic Islands: may acoustic devices be the solution to the problem? European Research on Cetaceans, Vol 15: 23-24.

Gazo, M., Gonzalvo, J. and Aguilar, A. (2008). Pingers as deterrents of bottlenose dolphins interacting with trammel nets. Fisheries Research, 92(1): 70-75.

Gearin, P. J., Gosho, M.E., Laake, J., Cooke, L., DeLong, R.L., Hughes, K.M. (2000). Phocoena phocoena, in the state of Washington. J.Cetacean Res. Manage., 2(1): pp 1-9.

Geijer, C. K. A. and Read, A. J. (2013). Mitigation of marine mammal bycatch in U.S. fisheries since 1994. Biological Conservation, 159(0): 54-60.

Gönener, S. and Bilgin, S. (2009). The Effect of Pingers on Harbour Porpoise, *Phocoena phocoena* Bycatch and Fishing Effort in the Turbot Gill Net Fishery in the Turkish Black Sea Coast. Turkish Journal of Fisheries and Aquatic Sciences 9: 151-157.

Götz, T. and Janik, V. M. (2013). Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. Marine Ecology Progress Series, 492: 285-302.

Hall, M. A. (1996). On bycatches. Reviews in Fish Biology and Fisheries, 6(3): 319-352.

Harwood, J. (1999). A risk assessment framework for the reduction of cetacean by- catches. Aquatic Conservation-Marine and Freshwater Ecosystems, 9(6): 593-599.

Jefferson, T. A. and Curry, B. E. (1996). Acoustic methods of reducing or eliminating marine mammal-fishery interactions: Do they work? Ocean & Coastal Management, 31(1): 41-70.

Kastelein, R. A., Goodson, A. D., Lien, J. and de Haan, D. (1995). The effects of acoustic alarms on harbour porpoises (*Phocoena phocoena*) behaviour. In: Nachtigall, P. E., Lien, J., Au, W. W. L. and Read, A. J. (Eds). Harbour Porpoises - Laboratory Studies To Reduce Bycatch. De Spil Publishers, Woerden, The Netherlands, pp. 157-167.

Kirkwood, R. and Goldsworthy, S. (2013). Fur Seals and Sea Lions. CSIRO PUBLISHING. p p 151

Koschinski, S., Culik,B. (1997). Deterring harbour porpoises (*Phocoena phocoena*) from gillnets: observed reactions to passive reflectors and pingers. Rep. int. Whal. Commn, 47: 659-668.

Kraus, S. D., Read, A. J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E. and Williamson, J. (1997). Acoustic alarms reduce porpoise mortality. Nature, 388: 525-526.

Larsen, F. (1999). The effect of acoustic alarms on the by-catch of harbour porpoises in the Danish North Sea gill net fishery. A preliminary analysis. IWC SC/51/SM41. International Whaling Commision Cambridge

Larsen, F., Krog, C. and Eigaard, O. (2013). Determining optimal pinger spacing for harbour porpoise bycatch mitigation. Endangered Species Research, 20(2): 147-152.

Larsen, F., Vinther, M. and Krog, C. (2002). Use of pingers in the Danish North Sea wreck net fishery. IWC SC/54/SM32. International Whaling Commision Cambridge

Lauriano, G. and Bruno, S. (2007). A note on the acoustic assessment of bottlenose dolphin behaviour around fishing gears in the Asinara Island National Park, Italy. Journal of Cetacean Resource Management, 9(2): 137-141.

Lopez, B. D. (2006). Interactions between Mediterranean bottlenose dolphins (*Tursiops truncatus*) and gillnets off Sardinia, Italy. Ices Journal of Marine Science, 63(5): 946-951.

Mangel, J. C., Alfaro-Shigueto, J., Witt, M. J., Hodgson, D. J. and Godley, B. J. (2013). Using pingers to reduce bycatch of small cetaceans in Peru's small-scale driftnet fishery. Oryx: 1-12.

Mate, B. R. (1993). Experiments with an acoustic harassment system to limit seal movements. Journal of the Acoustical Society of America, 94(3, Pt. 2): 1828.

Mate, B. R. and Harvey, J. T. (1987). Acoustical deterrents in marine mammal conflicts with fisheries. Oregon State Grant Publication ORESU-W-86-001. Sea Grant Communications, Oregon State University, Corvalis, Oregon.

McPherson, G. R., Ballam, D., Stapely, J., Peverell, S., Cato, D. H., Gribble, N., Clague, C. and Lien, J. (2004). Acoustic alarms to reduce marine mammal bycatch from gillnets in Queensland waters: optimising the alarm type and spacing. ACOUSTICS 2004, Gold Coast, Australia, 3-5 November 2004.

Monteiro-Neto, C., Avila, F. J. C., Alves, T. T., Araujo, D. S., Campos, A. A., Martins, A. M. A., Parente, C. L., Furtado-Neto, M. A. A. and Lien, J. (2004). Behavioral responses of *Sotalia fluviatilis* (Cetacea, Delphinidae) to acoustic pingers, Fortaleza, Brazil. Marine Mammal Science, 20(1): 145-151.

Murray, K. T., Read, A. J. and Solow, A. R. (2000). The use of time/area closures to reduce bycatches of harbour poporises: lessons from the Gulf of Maine sink gillnet fishery. Journal of Cetacean Research and Management, 2(2): 135-141.

Northridge, S., Kingston, A., Mackay, A. and 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, Sea Mammal Research Unit, St. Andrews

Northridge, S., Kingston, A., Murphy, S. and Mackay, A. (2008). Monitoring, impact and assessment of marine mammal bycatch. . Final report to Defra, Project MF0736. University of St. Andrews, Sea Mammal Research Unit, St. Andrews.

Northridge, S., Vernicos, D. and Raitsos-Exarchopolous, D. (2003). Net Depredation By Bottlenose Dolphins In The Aegean: First Attempts To Quantify And To Minimise The Problem.IWC SC/55/SM25, International Whaling Commision Cambridge

Orphanides, C. and Palka, D. L. (2013). Analysis of harbor porpoise gillnet bycatch, compliance, and enforcement trends in the US northwestern Atlantic, January 1999 to May 2010. Endang Species Res, 20: 251-270.

Pace, D. S., Pulcini, M. and Triossi, F. (2003). Interactions with fisheries: Modalities of opportunistic feeding for bottlenose dolphins at Lampedusa Island Itlay. http://www.oceanomaredelphis.org/drupal/publications/033_2003_Pace_etal_Interaction_with_fishery.pdf

Palka, D. L., Rossman, M. C., VanAtten, A. S. and Cd, O. (2008). Effect of pingers on harbour porpoise bycatch in the US northeast gillnet fishery. J. Cetacean Res. Manage, 10(3): 217-226.

Popov, V. and Klishin, V. (1998). EEG study of hearing in the common dolphin, Delphinus delphis. Aquatic Mammals, 24: 13-20.

Read, A. J., Drinker, P. and Northridge, S. P. (2006). Bycatch of Marine Mammals in U.S. and Global Fisheries Conservation Biology, 20(1): 163-169.

Reeves, R. R., Berggren, P., Crespo, E. A., Gales, N., Northridge, S. P., Sciara, G. N. d., Perrin, W. F., Read, A. J., Rogan, E., Smith, B. D. and Waerebeek, K. V. (2005). Global Priorities for Reduction of Cetacean Bycatch. WWF Workshop Report, 2005 - iucn.org.

Reeves, R. R., Read, A. and Notarbartolo di Sciara, G. (2001). Report of the workshop on interactions between dolphins and fisheries in the Mediterranean: evaluation of mitigation alternatives. ICRAM. Rome. pp.

Richter, C., Hood, C. and Lien, J. (1999). Mitigation of harbour porpoise bycatch with active acoustic devices in a non-experimental gillnet fishery. IWC SC/51/SM3, International Whaling Commision, Cambridge

Rocklin, D., Santoni, M., Culioli, J., Tomasini, J., Pelletier, D. and Mouillot, D. (2009). Changes in the catch composition of artisanal fisheries attributable to dolphin depredation in a Medinterranean marine reserve. ICES Journal of Marine Science, 66: 699-707.

Sagarminaga, R., Canadas, A. and Brotons, J. M. (2006). Initiatives about fisheries-cetaceans interactions in Spanish Mediterranean waters. IWC SC/58/SM13. International Whaling Commision, Cambridge. pp.

Schusterman, R. J., Balliet, R. F. and Nixon, J. (1972). Underwater audiogram of the California sea lion by the conditioned vocalization technique. Journal of the Experimental Analysis of Behavior, 17: 339-350.

Shapiro, A. D., Tougaard, J., Jorgensen, P. B., Kyhn, L. A., Balle, J. D., Bernardez, C., Fjalling, A., Karlsen, J. and Wahlberg, M. (2009). Transmission loss patterns from acoustic harassment and deterrent devices do not always follow geometrical spreading predictions. Marine Mammal Science, 25(1): 53-67.

SMRU, UCC, CFPO and ISWFO (2001). Reduction of porpoise bycatch in bottom set gillnet fisheries. Report to the European Commission Study Contract 97/095.

Soto, A. B., Cagnazzi, D., Everingham, Y., Parra, G. J., Noad, M. and Marsh, H. (2013). Acoustic alarms elicit only subtle responses in the behaviour of tropical coastal dolphins in Queensland, Australia. Endang Species Res., 20:271-282

Stone, G. S., Cavagnaro, L., Hutt, A., Kraus, S., Baldwin, K. and Brown, J. (2000). Reactions of Hector's dolphins to acoustic gillnet pingers. Department of Conservation, Wellington, New Zealand. DOC Miscellaneous Science & Research Publications. 28p. 2000., Publsihed client report on contract 3071 Funded by conservation services levy.

Trippel, E. A., Strong, M. B., Terhune, J. M. and Conway, J. D. (1999). Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. Canadian Journal of Fisheries and Aquatic Sciences, 56(1): 113-123.

van Marlen, B. (2007). Nephrops and cetacean species selection information and technology. NECESSITY Final Publishable Activity Report. IMARES, Wageningen. http://news.ices.dk/sites/eurepository/Shared%20Documents/FP6_NECESSITY/NECESSITY_501605_Publishable%20Final%20Activity%20Report.pdf.

Vinther, M. and Larsen, F. (2004). Updated estimates of harbour porpoise *(Phocoena phocoena*) bycatch in the Danish North Sea bottom-set gillnet fishery. J. Cetacean Res. Manag., 6(1): 19-24.

Waples, D. M., Thorne, L. H., Hodge, L. E. W., Burke, E. K., Urian, K. W. and Read, A. J. (2013). A field test of acoustic deterrent devices used to reduce interactions between bottlenose dolphins and a coastal gillnet fishery. Biological Conservation, 157(0): 163-171.

Werner, T., Kraus, S., Read, A. and Zollett, E. (2006). Fishing techniques to reduce the bycatch of threatened marine animals. Marine Technology Society Journal, 40(3): 50-68.

7. APPENDIX 1

Pingers which have resulted in significant reduction in bycatch rates of listed species in controlled trials in commercial fisheries

Pinger	**Source level (dB)**	**Frequency**	**Fishery**	**Bycatch Species**	**Reference**
Airmar	132	70kHz	Bottom set gillnet	Franciscana dolphin	Bordino *et al*. (2004)
Aquamark 100	145	20-160 kHz	Bottom set gillnet	Harbour porpoise	Larsen *et al.* (2013)
Aquamark 200	145	5-160 kHz	Driftnet	Striped dolphin	Imbert *et al.* 2007, cited in Dawson *et al.* (2013)
Dukane Netmark 1000*	132	10 kHz	Bottom set gillnet	Harbour porpoise	(Bordino *et al.* 2002, Gönener and Bilgin 2009, Kraus *et al.* 1997, SMRU *et al.* 2001, Trippel *et al.* 1999)
Dukane Netmark 1000*	132	10 kHz	Bottom set gillnet	Franciscana dolphin	Bordino *et al.* (2002)
Dukane Netmark 1000*	132	10 kHz	Driftnet	Common dolphin	(Barlow and Cameron 2003, Mangel *et al.* 2013)
DDD-03L	174	5-500 kHz	Bottom set gillnet	Harbour porpoise	(Northridge *et al.* 2011)
Future Oceans** Porpoise pinger	132	10 kHz	Driftnet	Common dolphin	(Carretta and Barlow 2011)

*The Dukane netmark 1000 is no longer made, but pingers with similar acoustic properties are available.

** The Future Oceans pingers were previously called Fumunda

8. APPENDIX 2

Pinger manufacturer websites (alphabetical)

Airmar http://www.airmartechnology.com

Aquatec http://www.aquatecgroup.com

Fishtek – Banana Pinger http://www.fishtekmarine.com

Future Oceans (previously Fumunda) http://www.futureoceans.com

Savewave http://www.savewave.eu

Seamaster http://www.seamaster.com.tw

STM products http://www.stm-products.com