REPORT NO. 3507

MIT2019-01 REVIEW OF DOLPHIN DISSUASIVE DEVICE MITIGATION IN INSHORE FISHERIES

CLIENT DRAFT

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CLIENT DRAFT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

Dolphin Dissuasive Devices (DDD) are thought to limit interactions between dolphins and fishing nets by emitting high frequency ultrasound signals that persuade animals to avoid the noise source. Signals can be modulated (in length and width) to limit the potential of dolphins becoming de-sensitised or adapting to the signal. While there is no quantitative data or evidence from New Zealand as to the efficacy of DDDs (Stone et al. 2000; Dawson & Lusseau 2005), there is anecdotal information that they may be effective in reducing dolphin bycatch in setnet fisheries (T. Clarke, pers. comm.). In New Zealand, DDDs are being used in the deep-water jack mackerel trawl fishery and also in some inshore set-net fisheries, targeting a range of different species, but their efficacy in these various settings have not been formally tested. However, there is some international evidence for their success in overseas fisheries (e.g. Dawson et al. 2013, Hamilton & Baker 2019).

The Cawthron Institute (Cawthron) was contracted by the Department of Conservation (DOC) to carry out a literature review of DDD use internationally and to provide recommendations for a potential experimental trial of these devices in New Zealand commercial fisheries. This project forms a part of the Conservation Services Programme Annual Plan 2019–2020.

1.1. Project scope

The project has the following main objectives:

1. Review of international literature of the types of DDDs used and their influence on bycatch events (summarised in a matrix), leading on to a specific review of New Zealand set-net and trawl fisheries with all protected New Zealand dolphin species, including Hector's and Māui dolphins
2. Develop a methodology for possible field trials and assessment of DDDs appropriate to an inshore fishery environment (i.e. set-net and trawl) to mitigate bycatch of HMDs
3. Propose recommendations for future research on the use of DDDs in the New Zealand inshore fishery with respect to bycatch mitigation of Hector's and Māui dolphins.

2. REVIEW FINDINGS

2.1. Literature review findings

Our literature search approach and evaluation criteria, as well as a breakdown of these findings for each criterion, can be found in Appendix 1. In addition, a summary of these specific publications and the nature of the information contained within each is provided in Appendix 3 and with an electronic version of the full database available from CSP[1].

The review identified 43 relevant research papers spanning the period 1998 to 2019 that discussed DDDs. Most were published scientific reports (77%) or government reports (16%). This review builds on the existing review papers that have considered the use and efficacy of DDDs (e.g. McPherson 2011; MacKay & Knuckey 2013; Dawson et al. 2013; Childerhouse et al. 2013; FAO 2018; Hamilton & Baker 2019). As a result, this document is laid out to complement and update the previous work presented in Childerhouse et al. (2013) which, while addressing mitigation options for set net fisheries, also covered DDDs. Since Dawson et al. (2013) and Childerhouse et al. (2013), only seven additional papers on DDDs have appeared in the literature. Perhaps unsurprisingly given the small amount of new research, the general conclusions of all these reviews have remained broadly consistent over this period.

There are many different ways to measure efficiency of DDDs. The two main areas of efficacy examined in this review corresponded to a direct reduction in bycatch levels and a direct reduction in target fish catch. There have been many DDD studies conducted over the last 20 years that have investigated the efficacy of DDDs in reducing marine mammal bycatch. However, there has been considerable variation in the success of DDDs in reducing bycatch. This wide range of results between studies are likely to be partly reflective of the range of different bycaught species, the different fishery types and locations covered. For example:

- The greatest success rate appears to be for beaked whales (Carretta et al. 2008) and harbour porpoises (*Phocoena phocoena*) (Alfaro Shigueto 2010; Gönener & Bilgin 2009; Northridge et al. 2011; Palka et al. 2008).
- There have been varying degrees of success for bottlenose (*Tursiops truncatus),* common (*Delphinus delphis*), striped (*Stenella coeruleoalba*) and franciscana dolphins (*Pontoporia blainvillei*) (reviewed by Dawson et al. 2013).
- There has been little or no evidence of success for Hector's (*Cephalorhychus hectori*) (Stone et al. 1997, 2000), Indo-pacific humpback (*Sousa chinensis*) (Berg Soto et al. 2009; Soto et al. 2012) and tucuxi dolphins (*Sotalia fluviatilis*) (Monteiro-Neto et al. 2004) although there have been only limited studies on these species.

[1] Database available from csp@doc.govt.nz

As a result of considerable previous research (e.g. Kraus et al. (1997); Carretta & Barlow (2011); Palka et al. (2008); Northridge et al. (2011); Orphanidea & Palka (2013)), DDDs are currently mandatory in several commercial fisheries, including the Gulf of Maine groundfish gill net fishery and the California drift net fishery under various 'Take Reduction Plans' (NOAA 2013a, 2013b) and also in some fisheries in the European Union (e.g. EU standard 2016/0074). The mandatory use of DDDs in the California drift net fishery was concluded to be the primary reason for the recorded 100% decline in bycatch rates of beaked whales over the course of 17 years of observations, rather than other mitigation techniques applied during the same period, which included seasonal closures and limitations on fishing depth (Carretta et al. 2008).

Bycatch rates of harbour porpoise were found to be significantly reduced in several studies, although the statistical power of these results vary (see Appendices 1 and 3 for details). In a large dataset from the NE Atlantic, Palka et al. (2008) found DDDs resulted in significantly less bycatch, but only in the absence of DDD failure. For example, those nets with an incomplete set of DDDs had greater bycatch than those with none, and it was suggested that porpoises may perceive a gap in functioning DDDs as a gap in the net. Bycatch reduction for this species because of DDDs has also been demonstrated in the Black Sea (Gönener & Bilgin 2009) and Peru (Alfaro Shigueto 2010). Two simulated studies of DDD effectiveness found a significant decrease in the echolocation rate of porpoises around active DDDs (Berggren et al. 2009; Hardy et al. 2012). EU regulations require vessels > 12 m in length to use DDDs on static nets to minimise risk to cetaceans. While the use of DDDs has proved effective for harbour porpoises, fishers are concerned with the impracticalities of using such a high number of devices (Northridge et al. 2011). Tests of louder DDDs have suggested that they may be effective over up to 10 times the distance as standard DDDs, but bycatch reduction rates were not as high (e.g. ~65% with louder devices compared to ~90% with standard devices, Northridge et al. 2011). However, the authors suggested further testing was needed as sample sizes were too small to be statistically robust. Larsen et al. (2013) conducted a controlled experiment testing the effect of increased DDD spacing on harbour porpoise bycatch in the Danish North Sea. Current regulations at that time required DDDs to be spaced no more than 200 m apart, but this study found spacing at 455 m resulted in 100% bycatch reduction compared to fishing without DDDs.

Most studies examining bottlenose dolphins focused on depredation of prey from nets rather than bycatch rates. Depredation causes economic losses to the fishery through reduced catch and net damage, as well as conservation concerns, as animals often become entangled. Studies show varied responses by bottlenose dolphins to DDDs, with some indications of a decrease in net damage and greater target species catch (Brotons et al. 2008b; Buscaino et al. 2009; Gazo et al. 2008) and decreased interaction rates (Waples et al. 2013). However, as Dawson et al. (2013) highlighted, there have been two other studies where fatal entanglements of bottlenose dolphins continued to occur in nets equipped with DDDs (Northridge et al. 2003; Read & Waples 2010).

Common dolphin response to DDDs has also been inconsistent as highlighted by Berrow et al. (2008). This simulated study on the south coast of Ireland found no evidence of avoidance to active DDDs, while Carretta & Barlow (2011) found a 50% reduction in common dolphin bycatch with DDDs use in the Californian gill net fishery.

Overall, there were 10 references from the review that demonstrated both a decrease in bycatch levels and no change in target fish catch levels. While all the data from the references considered in the review were considered in investigating the efficacy of DDDs, a 'successful' study was deemed to be one that also had a moderate to high degree of scientific rigor in addition to a reduction in capture/ catch rates. Eight references met these requirements and are used to summarise some of the key features of a robust research programme that successfully demonstrated the efficacy of DDD in reducing bycatch (Figure 1, Table 1). To try and investigate the overall pros and cons of these projects, these two primary factors were combined with project cost (see Appendix 1, Section A1.2.7). Based on the data presented in Figure 1, there does not appear to be any clear or consistent patterns demonstrating successful studies' ability to reduce capture rates relative to the different costs categories.

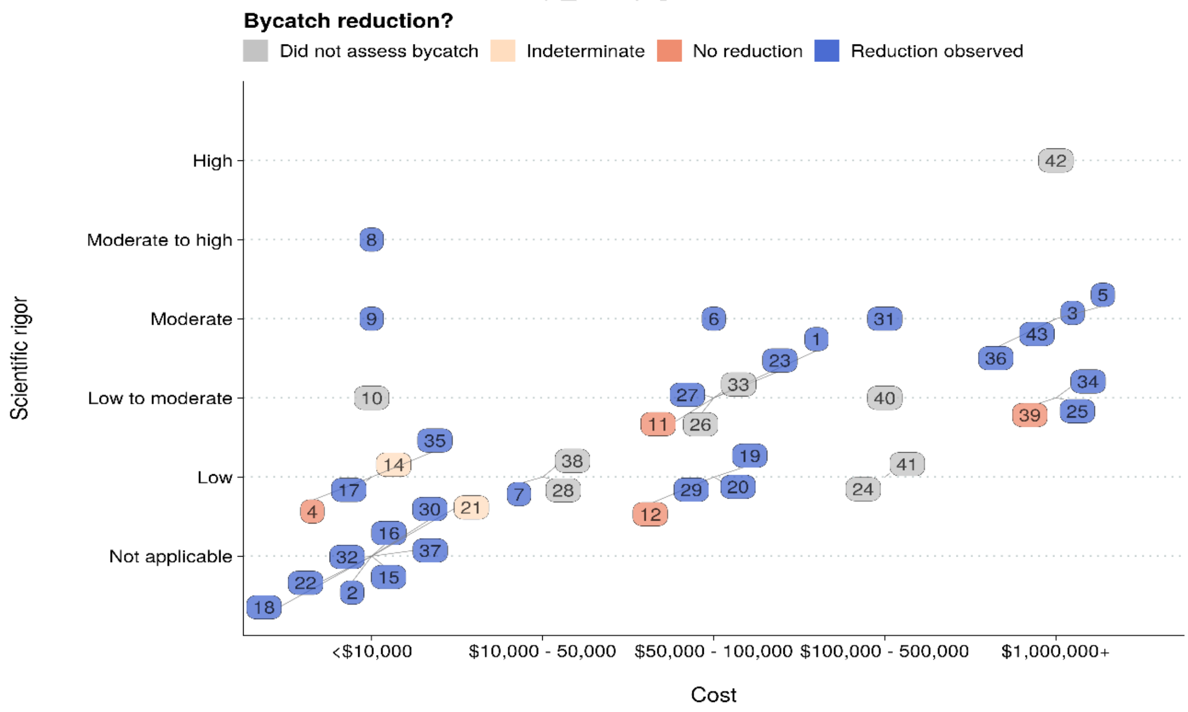

Figure 1. Investigation of the relationship between scientific rigor (Y axis), estimated project cost (X axis) and efficacy of the DDD in reducing bycatch (see legend for an explanation) from a review of 43 research papers covering DDD studies. The number inside the circles corresponds to the number of the research paper summarised in Table 1 and Appendix 3. Note: Points have been spread out to avoid overlap so they can be clearly read.

It is also important to consider that studies or experiments that do not achieve a significant or interesting result are unlikely to be published as a general rule. Therefore, it is possible that a range of other studies that have not demonstrated efficacy may not have been published. Hence, the available literature is likely to represent a more positive assessment of the efficacy of DDDs than potentially the greater body of work undertaken.

Table 1. Summary of DDD studies that are considered to have a moderate or high degree of scientific rigor and robustly demonstrated a reduction of capture rates. The reference number corresponds to the number of the paper as covered in Appendix 3.

Reference number	**Reference**	**Year**	**Study name (DDD type)**	**Gear codes**	**Species**	**Key finding**	**Exhibited avoidance?**	**Bycatch reduction**	**Maintained target catch**	**Level of efficacy**	**Costs**
3	Barlow and Cameron 2003	2003	Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery (Dukane NetMark 1000)	Set-net	Dolphins & pinnipeds	Pingers significantly reduced total cetacean and pinniped entanglement in drift gill nets without significantly affecting swordfish or shark catch, results also indicate a greater reduction with a greater number of pingers. For species tested separately with this test, bycatch reduction was statistically significant for short beaked common dolphins (P = 0.001) and California sea lions (P = 0.02). Bycatch reduction is not statistically significant for the other species tested separately, but sample sizes and statistical power were low, and bycatch rates were lower in pingered nets for six of the eight other cetacean and pinniped species. For a net with 40 pingers, the models predict approximately a 12- fold decrease in entanglement for short-beaked common dolphins, a 4-fold decrease for other cetaceans, and a 3-fold decrease for pinnipeds	Y	77%	Y	Pingers significantly reduced total cetacean and pinniped entanglement in drift gill nets without significantly affecting swordfish or shark catch. *We believe that pingers are unlikely to reduce the bycatch of all cetacean species or all pinniped species.*	$1,000,000+
5	Bordino et al. 2002	2002	Reducing incidental mortality of Francisana dolphin *Potoporia blainvillei* with acoustic warning devices attached to fishing nets (Dukane NetMark 1000) .	Set-net	Franciscana	A highly significant reduction in bycatch for this species. However, sea-lions (*Otaria flavescens)* damaged the fish in active pinger nets significantly more than silent nets, and the damage increased over the course of the experiment. 61% of entangled dolphins were females and 56% of the females were immature. Necropsies also revealed that 5 of 17 retrieved females were pregnant. Among males 90% were immature. Entangled dolphins were not eating the target species of the fishery.	Y	84%	N	The alarms were effective at reducing the incidental mortality of the Franciscana dolphin in bottom-gillnets in the study area. Entangled dolphins were not eating the target species of the fishery, but sea lion depredation increased.	$1,000,000+

Reference number	Reference	Year	Study name (DDD type)	Gear codes	Species	Key finding	Exhibited avoidance?	Bycatch reduction	Maintained target catch	Level of efficacy	Costs
6	Brotons et al. 2008b	2008	Do pingers reduce interactions between bottlenose dolphins and nets around the Balearic Islands? (Aquatec AQUAmark 210)	Set-net	Bottlenose dolphins	Net interaction rates were significantly reduced by 49% with active pingers, but not all brands were equally effective. Catch yields were increased by 9% with active pingers, though not significantly. The largest increase in PPUE was seen in the conditions where pingers were inactive. As previous work on this fishery has shown that there is a strong seasonal effect on both dolphin-net interaction rates and profit per unit effort, PPUE (Brotons et al. 2007), While all brands showed some reduction in the active condition compared to the no-pinger control, only the reduction for Aquatec pingers was significant ($p = 0.0064$, Table 3). These pingers reduced the net interaction rate by 70% in active nets. We have shown that pingers may have potential as an effective mitigation measure, but our results are not conclusive and additional research must be conducted. If pingers are introduced, long-term study will be absolutely essential to monitor the impact of pingers on mortality levels and to monitor the possibility of habituation and/or sensitisation to the pinger stimuli. Furthermore, the widespread introduction of pingers into this fishery would significantly change the acoustic ecology of Balearic coastal waters and monitoring the effects of this change on the dolphin population would be important.	Y	49%	NA	Shows potential for reducing net interactions, but requires further research	$50,000 - 100,000
8	Carretta & Barlow 2011	2011	Long-term effectiveness, failure rates, and “dinner bell” properties of acoustic pingers in a gillnet fishery (Not specified)	Set-net	Dolphins & Pinnipeds	The proportion of sets with cetacean bycatch was significantly lower ($p = 6.7 \times 10^{-7}$) in sets with ≥30 pingers (4.4% of sets with bycatch) than in sets without pingers (8.4% of sets). Common dolphin bycatch rates on sets with ≥30 pingers were nearly 50% lower than those without pingers. Bycatch of other cetaceans was not significantly affected by pinger use; however, sample sizes were small. Beaked whales were not observed bycaught since 1 year prior to pinger use. Bycatch was 10x greater when >1 pinger failed. Over 14 years there was no evidence of habituation.	Y	50%	NA	The proportion of sets with cetacean bycatch was significantly lower in sets with ≥30 pingers (4.4% of sets with bycatch) than in sets without pingers (8.4% of sets).	<$10,000
9	Carretta et al. 2008	2008	Acoustic pingers eliminate beaked whale bycatch in a gill net fishery (Not specified)	Set-net	Beaked whales	Beaked whale bycatch dropped from 33 beaked whales in 3303 sets during the first 6 years of the observer program, to none in 4381 sets over the last 10 years while pingers were in use. Results suggest beaked whales may be among the most sensitive cetacean taxa to pinger frequencies. The difference in beaked whale entanglement rates with and without pingers is so large that it cannot be explained as a sampling artifact (though population decline of toothed whales needs to be considered). In contrast, bycatch rates of all cetaceans (mostly dolphins) decreased by only 50% over the same period.	Y	90%	NA	Beaked whale bycatch dropped 100%, bycatch rates of all cetaceans (mostly dolphins) decreased by only 50% over the same period	<$10,000

Reference number	Reference	Year	Study name (DDD type)	Gear codes	Species	Key finding	Exhibited avoidance?	Bycatch reduction	Maintained target catch	Level of efficacy	Costs
31	Mangel et al 2013	2013	Using pingers to reduce bycatch of small cetaceans in Peru's small-scale driftnet fishery (Dukane NetMark 1000)	Set-net	Dolphins	We have shown that pingers were effective at reducing bycatch of small cetaceans in the Peruvian small-scale driftnet shark fishery. Given the vast size of this fishery and its current levels of bycatch of small cetaceans (Alfaro-Shigueto et al., 2010; Mangel et al., 2010) appropriate use of pingers could result in mortality reductions of thousands of individuals per annum and would represent an important step for the conservation of small cetaceans in the south-eastern Pacific. There was no statistically significant difference in catch rates of sharks and rays, the primary target species in this fishery, between control and experimental sets	Y	37%	Y	Pingers reduced bycatch of small cetaceans in the Peruvian small-scale driftnet fishery. Most dramatically for the common dolphins. There was no statistically significant difference in catch rates of sharks and rays, the primary target species in this fishery, between control and experimental set	$100,000 - 500,000
36	Palka et al. 2008	2008	Effect of pingers on harbour porpoise (*Phocoena phocoena*) bycatch in the US Northeast gillnet fishery (Not specified)	Set-net	Harbour porpoises	Bycatch rates in hauls without pingers were greater than those with the required pingers. Unexpectedly, when hauls had an incomplete set of pingers, bycatch was greater than those without pingers altogether. As mesh size increased so did bycatch rate, despite the presence of pingers. All observed bycatch was in nets of >15 cm mesh size. No evidence of temporal trends in bycatch, suggesting no habitation so far	Y	50%	IND	Support that pingers can reduce harbour porpoise bycatch, even in an operational fishery. Uses fishing effort as a proxy for target catch rates, but not clear if this was maintained or not.	$1,000,000+

Reference number	Reference	Year	Study name (DDD type)	Gear codes	Species	Key finding	Exhibited avoidance?	Bycatch reduction	Maintained target catch	Level of efficacy	Costs
43	Waples et al. 2013	2013	A field test of acoustic deterrent devices used to reduce interactions between bottlenose dolphins and a coastal gillnet fishery (SaveWave White & Black)	Set-net	Bottlenose dolphins	Fish catch was significantly lower when dolphin interactions were observed. Pingers did not affect fish catch, but dolphin interaction decreased, and echolocation increased with active pingers. The durability of pingers however, is not sufficient for effective deployment in this fishery.	Y	49%*	Y	SaveWaves were effective in deterring dolphins from interacting with Spanish mackerel gillnets, although the observations from the research vessel indicate that the ADDs did not eliminate this behaviour entirely. Pingers did not affect fish catch, but dolphin interaction decreased, and echolocation increased with active pingers	$1,000,000+

* Bycatch rates were not reported, and this reflects value a reduction in interaction rate

2.1.1. Potential effects of DDDs on dolphins

One of the main issues involved with the use of acoustic deterrents is the chance of habituation, where the behavioural responses of animals lessen over long-term exposure. Some long-term studies have found no evidence of this in active fishery scenarios (Carretta & Barlow 2011; Palka et al. 2008), while Berggren et al. (2009) detected some signs of habituation during their simulated trial. The risk of habituation occurring is likely even greater, if some reward such as prey, is to be gained by ignoring the deterrent. For instance, there are concerns that for some species, particularly pinnipeds (e.g. Bordino et al. 2002), that acoustic deterrents may act as a 'dinner bell' associated with an easy source of food. However, there is mixed evidence for this type of response, and it is likely to vary considerably by pinniped species (Carretta & Barlow 2011).

Another potential risk includes habitat exclusion. If DDDs are used extensively and repeatedly in preferred habitat areas of bycatch species, there is potential for animals to be denied access to important areas. This is likely to be more of a threat to coastal species such as Hector's and Māui dolphins, which have small home ranges to begin with (Dawson et al. 2013).

DDDs have appeared to be very effective in reducing beaked whale bycatch (Carretta et al. 2008) and these results indicate how sensitive these species are likely to be with respect to anthropogenic sound in general. However, one caveat with this study is that DDDs were implemented alongside a range of other mitigation techniques (e.g. time-area closures and gear modifications) and therefore the resulting reduction in bycatch is likely to reflect the full range of mitigation techniques rather than simply the introduction of DDDs, although the authors robustly concluded that DDDs were the primary reason for the decline in bycatch levels.

There is potential for DDDs to increase noise pollution in the environment. Minimising this impact is one reason for testing and determining the minimum number and spacing of DDDs needed to reduce bycatch. Using more DDDs than required will not only increase noise pollution unnecessarily but could greatly increase overhead costs to fisheries and affect practicality (Larsen et al. 2013; Northridge et al. 2011). Tests of a louder acoustic device on small cetacean bycatch in the United Kingdom (Northridge et al. 2011) have appeared effective in terms of reducing the number of devices needed, with estimates of effective range ranging between 400 m for standard DDDs to between 1.2 and 3 km for louder DDDs (i.e. ~165 dB re 1µPa@1m) (Northridge et al. 2011). The addition potential impact of using louder DDDs and introducing more noise into the ocean is not well understood and should be a consideration for any research.

2.1.2. Potential effects on fisheries

While DDDs have shown some success in mitigating bycatch, they come with associated costs for fisheries, particularly when used extensively. These devices are relatively expensive in terms of the cost of initial setup and maintenance. Northridge et al. (2011) estimated that depending on the DDD model used, the amount of DDDs required per net and the fisheries to be covered, costs for implementing DDDs could range from between NZD$230,000 to NZD$5.1 m to fisheries. Similarly, even trials of devices can be cost-prohibitive. This is particularly the case for fisheries with relatively low bycatch rates, as a large number of trial sets would need to be conducted in order to gain sufficient statistical power to determine effectiveness (Dawson et al. 2013). Several studies have highlighted concern for the robustness of DDDs and the extent of their battery life (Alfaro-Shigueto 2010; Carretta & Barlow 2011; Hardy et al. 2012; Orphanides & Palka 2013; Waples et al. 2013). Maintaining a large number of these devices can prove costly in terms of both repairs and downtime (e.g. vessel being unable to fish if sufficient working DDDs are not available) (Alfaro-Shigueto 2010, Northridge et al. 2011; Waples et al. 2013). Additionally, Northridge et al. (2011) reported safety concerns for crew members as DDDs become entangled in gear.

2.1.3. The application of DDDs in New Zealand

Some DDDs have been trialled in New Zealand fisheries (Stone et al. 1997, 2000; Dawson & Lusseau 2005) and had mixed results. DDDs have been used sporadically in the New Zealand set net fishery (Ramm 2010, 2011); however, low observer presence and lack of compliance prevented conclusions being made on their efficacy in reducing bycatch of protected marine species. Nonetheless, DDDs are being used under voluntary Codes of Practice by some commercial fishers. A review by Dawson et al. (2013) of previous DDD studies undertaken on Hector's dolphins found that there was no evidence that they were physically displaced from moored DDDs, but avoidance reactions were observed in 66% of nearby dolphin groups when a DDD was immersed from a drifting boat. However, this latter result was questioned in that boat-based trials may provide poor measures of responses to DDDs, given the possible confounding effect of the vessel, the potential for dolphins to be startled by the sudden onset of DDD sounds at close range (e.g. see Teilmann et al. 2006), and that they do not mimic the behavioural context associated with nets that are actively fishing (Dawson et al. 2013).

DDDs appear most successful for cetaceans that are neophobic (i.e. fear of anything new) or easily startled and have large home-ranges (Dawson et al. 2013). Therefore, they are more likely to be effective for phocoenids (i.e. porpoises) than coastal delphinids, and it is unreasonable to expect that DDDs will work with all small cetaceans. Based on these assumptions, DDDs are, therefore, likely to be a less effective mitigation technique for Hector's and Māui dolphins. An equally important consideration is that, with the possible exception of beaked whales for which bycatch has been eliminated, even if DDDs are able to deter Hector's or Māui dolphins, could they achieve and consistently sustain an acceptable level of bycatch reduction? The required reduction for Māui dolphins would need to be 100% and a similarly high level would need to be achieved for Hector's dolphin (Slooten 2013). Based on the available evidence, it seems that attaining these levels with the use of DDDs alone is not presently feasible. Dawson et al. (2013) noted that the risks of even undertaking a trial on these populations could be significant given sample sizes that would be required to demonstrate their effectiveness (e.g. positive or negative).

MPI and DOC (2012) reviewed the use of DDDs as a mitigation technique for Maui dolphins and arrived at the following conclusion:

> The use of DDDs to reduce interactions between Hector's dolphins and set nets has been investigated and MPI considers the efficacy of these devices to be unproven for Maui's dolphins. DDDs have proven to be effective for some cetacean species but have not been conclusively established as effective for Maui's or Hector's dolphins. It is also not known what undesired impacts DDDs may cause, for example exclusion of the Maui's dolphins from their natural habitat and foraging areas. MPI considers any benefits these devices would provide to be unknown and unclear, which could result in unnecessary costs being imposed on industry. If the use of DDDs was required off the WCNI [West Coast North Island], data collection on the efficacy of this practice would also be required. However, such data collection is unlikely to be feasible given the small population size of Maui's dolphins. Requiring the use of DDDs alone would not be sufficient to determine whether or not DDDs are effective in reducing the risk of fishing-related mortality from set nets.

This statement is now 8 years old and it is unclear if this position has changed since that time as no similar statement has been made recently.

2.2. Commercial set-net and trawl fisheries that catch Māui and Hector's dolphins

Of the two sub-species, only Hector's dolphins have been reported caught in both set-net and inshore trawl fisheries, but the actual observed catches are few (Figure 2). Either zero or one capture have been observed in most years from set-nets. No individuals have been reported as caught from trawlers with observers although there has been some self-reporting from trawl fishers after catching Hector's dolphins. Observer coverage in those two fisheries is low (Figure 3) especially for set-net fishing. This limits the potential to record encounters, although observer coverage has been increasing since 2002/03. Fishers have not reported captures so far when there was no observer on-board (source: PSC databases), and therefore, unobserved fishing effort is of limited use to quantify the true number of encounters with fishing gear.

No encounters with Māui dolphins were observed or reported by fishers in any fishery.

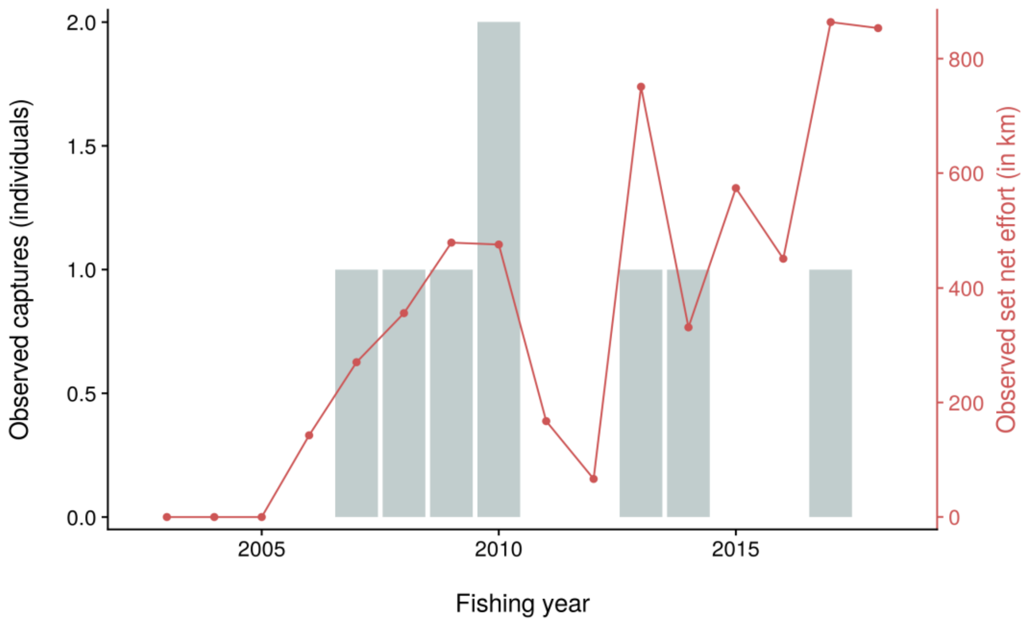

Figure 2. Annual number of captures of Hector's dolphins for all observed set-net (all target species combined) effort by fishing year (grey) with the total amount of nets with observer coverage (red).

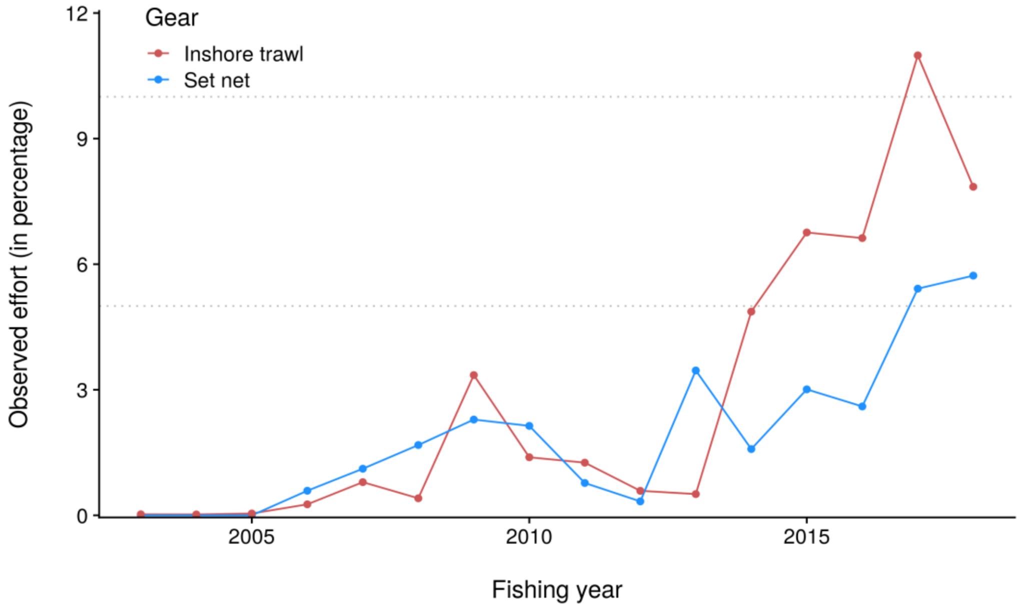

Figure 3. Observer coverage as a percent of the total kilometres of net observed for set-net (red), and percent of total trawls observed for inshore trawl (blue)

Roberts et al. (2019) modelled the expected number of fleet-wide encounters with Hector's dolphins from observed sets and found, for these dolphins, that there should have been between 39 and 71 individual mortalities from set-nets depending on the year (Figure 4), and between 14 and 42 individuals mortalities by inshore trawl (mean prediction; Figure 5). When compared to the total fishing effort, this equates to one individual captured per 400 km of set-net, and one individual captured per 3000 inshore trawls. These values reflect the mean value over the last five years.

The relatively low level of estimated bycatch for Hector's dolphins is even lower for Māui dolphins. In Roberts et al. (2019)'s application of their model to this species, they found that less than one individual would be expected to be caught per year from both trawl and set-net effort.

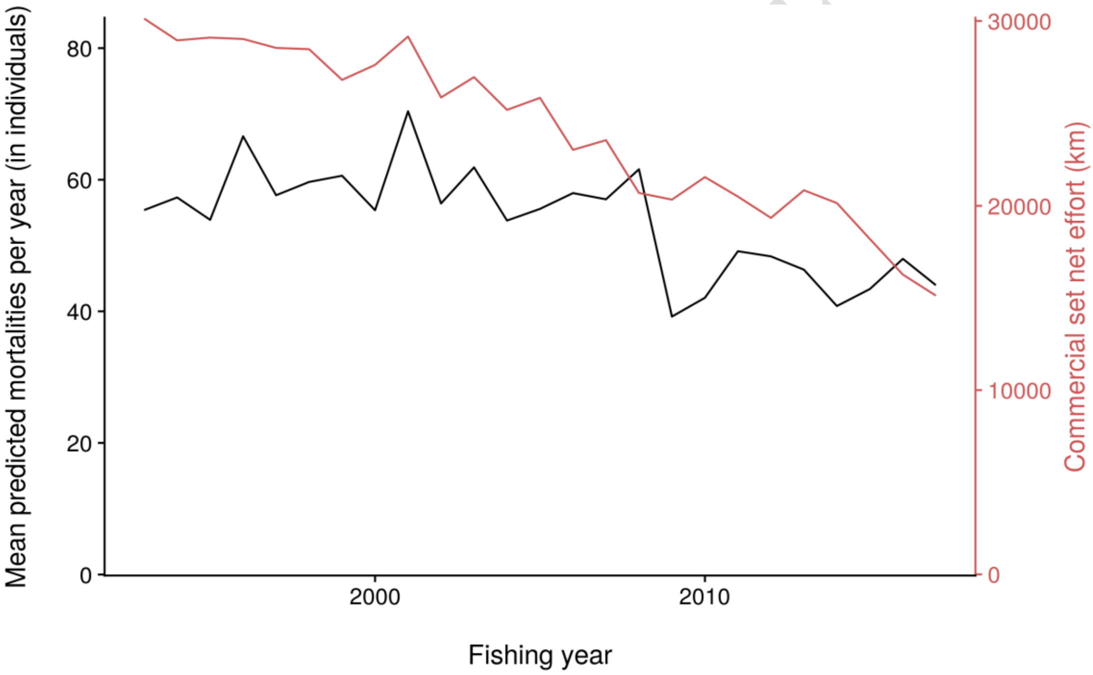

Figure 4 Mean predicted Hector's dolphin mortality (black) from commercial set-net effort from Roberts et al. (2019). The set-net effort (red; in km) is included for context. Note that the effort values reported here are the values that were used as part of the Roberts et al. model and therefore may not exactly match statistics reported elsewhere.

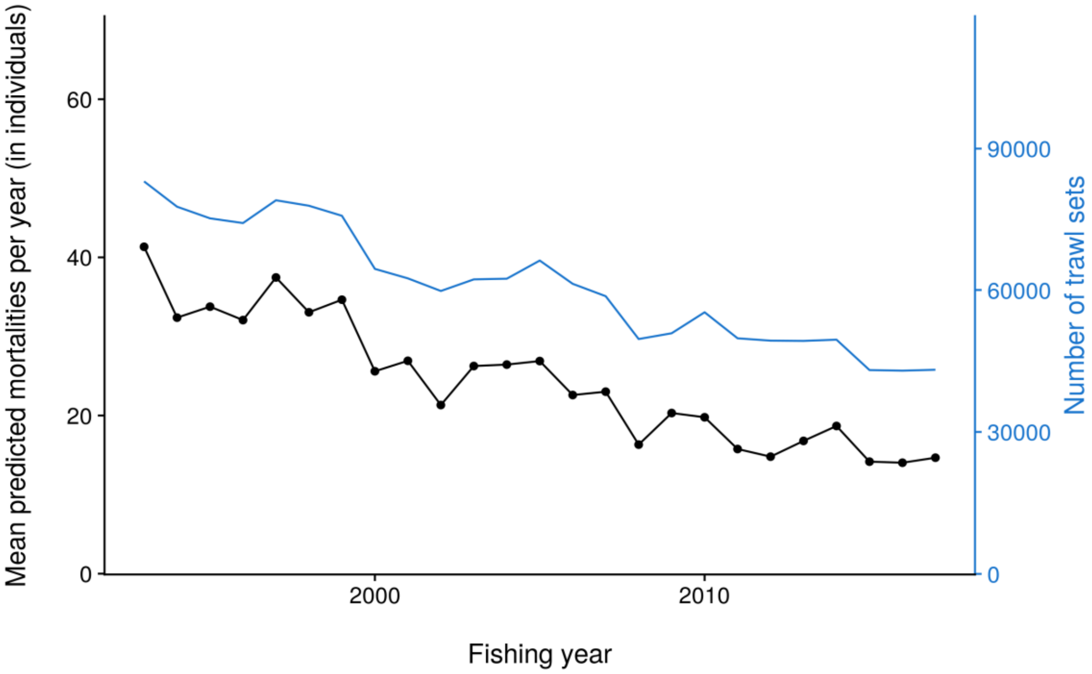

Figure 5 Mean predicted Hector's dolphin mortality (black) from inshore trawl effort from Roberts et al. (2019). The trawl effort (blue; in sets) is included for context. Note that the effort values reported here are the values that were used as part of the Roberts et al. model and therefore may not exactly match statistics reported elsewhere.

2.3. Review of existing DDD use in New Zealand

Dawson & Slooten (2005) provide a summary of the use of DDDs at that time:

> Nevertheless, Canterbury fishermen voluntarily use pingers under a 'Code of Practice' (Southeast Finfish Management Company, 2000) which, in addition to pinger use, encourages the setting of nets with the tide and the avoidance of setting nets in depths of less than 30m or when dolphins are around the vessel; it also advises on what might reasonably be considered best practice. In addition, some gillnetters have voluntarily shifted their fishing operations away from areas with high densities of Hector's dolphins. It has been difficult, however, to ensure that pingers are used as required. While most of the skippers in the Canterbury gillnet fleet (Motunau to Timaru) have been cooperative, one refused to carry observers. Another insisted that it was dangerous for his crew member to attach pingers to the net as it is set. Since he believed that setting and hauling operations pose the greatest risk, he dangled pingers from his boat during these times. His nets, when set, were unalarmed. Of the 68 gillnet sets observed in Canterbury in 1999/2000, only 28% complied with the COP instructions for pinger deployment (Blezzard, pers. comm.). It is in the nature of fishermen to vary practices to find what seems the best solution, but this can mean that it is difficult to ensure effective use by everyone.

NOTES TO BE ADDED FROM DISCUSSIONS WITH DAVE JAMES (MARINTEC) AND TOM CLARK

3. EXPERIMENTAL TRIALS

We identified a range of issues that need to be considered when designing trials for testing the efficacy of DDDs to mitigate bycatch of Hector's and Māui dolphins. An analysis and overview of these issues is provided in Appendix 2 with a summary provided in this Section.

The design of a robust trial requires the consideration of a wide range of potential issues. Based on this review, the following elements were identified as being essential to the development of a robust experiment trial:

- strong experimental design including use of appropriate controls and double blind experiments
- use of independent government observers and / or independent scientists to provide robust and accurate monitoring data
- large sample sizes (e.g. > 25% of all fishing effort)
- consideration and monitoring of range of potential variables and fixing variables wherever possible
- formal necropsies of dead individuals for which cause of death was not able to be directly confirmed
- multi-year and multi-regional studies and consideration of issues such as habituation. In particular, use of long term, existing, robust data sets to establish base line capture rates is particularly useful
- calculation of statistical power for results to aid in accurate interpretation of any significant (and non-significant) results
- concurrent monitoring of commercial fish catch as an essential part of the trial to demonstrate any impact on catch
- clear instructions and communication provided to all parties involved in the trials (e.g. fishers, observers, managers) to ensure experimental designs are implemented accurately (e.g. to ensure comparability between vessels, areas, and years) including appropriate training
- needs to be well-funded. Most of the research that provided a robust fishery level result utilised existing government observer programmes that were estimated as exceeding US$1 million in value.

One fundamental issue is the social license-based expectation that any trial should not result in an increase in capture rates and that any trial would not progress without good evidence to confirm that this would be the case. Extending this concept further, it would be unethical to undertake trials on Māui dolphin due to their critically endangered status and therefore, by default, any trials would need to be undertaken on HDs. Being able to establish that a DDD will not increase capture rates with a high degree of certainty prior to moving into fisheries trial, necessitates a staged approach to research starting with simple experiments to demonstrate potential efficacy without any risk to dolphins.

Utilising a staged approach to research, a series of experiments with increasing levels of complexity is recommended. A staged approach would include the following components with moving to the next stage based on positive results from the previous stage:

1. **Testing the in water operation of one or more different types of DDDs**. Research would cover issues such as: (i) measuring the reliability of DDDs (e.g. do they operate consistently as designed over long time periods and are they robust enough to survive placement in operational fisheries), (ii) assessing battery life, (iii) confirming pulse frequencies and loudness, and (iv) measuring effective detection distances (e.g. underwater sound propagation). Experiments could be as simple as deploying active DDDs on multiple moorings alongside acoustic recorders for several days to record DDD sound production. This could be supplemented by acoustic recordings taken from a mobile acoustic recorder at known distances and depths from the DDD to describe propagation and the sound field. This would be relatively cheap, simple, and straight forward to achieve. *Estimated cost NZD$10-15k.*

2. **Testing simple responses of HDs to active DDDs**. Research would address whether the DDD elicits a response in a HD. There are a range of possible research that could be undertaken:
   a. land based theodolite tracking of dolphin movements around a DDD programmed to turn on and off at random intervals[2] comparing closest approach data to avoid auto-correlation of sightings. This is similar to the approach trialled on HDs by Stone et al. (1997) with a good example of this kind of study provided in Berg Soto et al. (2009). *Estimated cost NZD$50-65k.*
   b. simply lowering a DDD programmed to turn on and off at random intervals into the water while monitoring dolphin behaviour with a focus on assessing avoidance and surfacing positions. This is similar to the approach trialled on HDs by Stone et al. (1997) with a good example of this kind of study provided in Hardy & Tregenza (2010). *Estimated cost NZD$25-35k.*
   c. boat based line transect surveys through areas of high HD density towing a DDD programmed to turn on and off at random intervals while observers collect data on dolphin activity and distance to the vessel. This is a new area of research and not being trialled previously. *Estimated cost NZD$20-30k.*

[2] Some DDDs have this ability while others do not so choice of DDD to trial would be important. Alternative it may be possible to work with DDD manufacturers to provide some modified DDDs for testing purposes.

An important and desirable inclusion is blind testing whereby the researchers do not know when the DDD is on or off. Some potentially useful extensions would include (i) the concurrent use of acoustic recorders in each of these projects to collect data on both the performance of the DDD and dolphin vocalisations and (ii) the use of a drone or fixed cameras to collect video footage of behaviour and potentially location data (i.e. distance of a surfacing dolphin from the DDD or vessel). It is important to be aware that any results from vessel based research is likely to include a component of vessel effect given the boat-positive nature of HDs. This needs to be accounted for in any project that uses a vessel. A critical consideration for research is testing for habituation which will require at least multi-week if not multi-month long projects. Stage 1 could be undertaken anywhere whereas Stage 2 should be undertaken in an area of high HD density such as Banks Peninsula.

3. **Exploratory data analysis**. Prior to starting *in situ* fishery trials, it is important to undertake statistical power analysis to establish likely sample sizes required for a robust trial. These analyses can be based on the effect sizes estimated in Stage 2, known or estimated capture rate, the spatial and temporal distribution of fishing effort and other relevant features. Ideally a spatially explicit model should be developed to identify potentially different sampling strata and to optimise sample strategies to maximise data collection. In addition, it is important to estimate the likely benefit of the implementation of the DDD to population level questions (i.e. will the expected improvement in capture rate translate into significant, positive population growth or at least a reduction in the rate of decline). Following on from this modelling, it would be useful to estimate the budget required for the next two stages to support decisions as the project can then be assessed against other mitigation options and potential management actions with some consideration of cost-benefit analysis.

   If there is a chance that the trial could lead to increased capture rates (e.g. dolphin prey and/or dolphins are attracted to DDDs), then moving into fishery trials could lead to increased dolphin deaths. The level of uncertainty around this parameter is one of key parts of the assessment process and therefore needs to include an element of risk assessment.

   A key step prior to starting the assessment process is to develop clear criteria for determining the success of a trial (e.g. trials must demonstrate that > 50% dolphins avoid areas with active DDDs and that 0% of dolphins were attracted to active DDDs). There are many possible criteria which could be applied, and these are must be scientifically driven while noting that management drivers (e.g. economic considerations) will also be important. These will also need to reflect and consider the level of uncertainty that is deemed acceptable. If these criteria are met, then progress to stage 3.

   It is also recommended that overseas researchers who have extensive experience in DDD and fishery related trials be included in the design and interpretation of this analysis to ensure that New Zealand builds on existing expertise available around the world.

4. **Pilot trial in fishery**. A pilot study should be undertaken in an area with a high level of interactions (e.g. Banks Peninsula – see [add reference]) over a sufficient enough time period to provide a robust result. There are a range of suitable and published research models from existing fisheries (e.g. Palka et al. 2008) that can be used to develop a structured programme. It is necessary to have clear triggers for management action developed prior to the start of the trial (e.g. trial halted if capture rates increase). Once the necessary sample size has been collected, results are analysed and, based on results and success criteria, determine if it is appropriate to move to the next stage. It is also worth mentioning that any research study should be conducted outside of all existing closed areas in areas where fishing is allowed.

5. **Full trial in fishery**. Expand the pilot project and modify as required based on experience from the pilot. Rerun the modelling developed for Stage 3 which can now be populated with measured rather than estimated parameters and increase the spatial and temporal coverage of the trial. Continue with full trial until data confirms the success or otherwise of the project (based on pre-determined success criteria) and take an adaptive management approach based on the best available data.

Conclusions: The most effective approach to a trial for DDDs and Hector's and Māui dolphins is to take a staged approach with successive stages building in both complexity and risk. The initial three stages should represent no additional risk to Hector's and Māui dolphins during their implementation and therefore could be progressed immediately. Stages 4 and 5 include intrinsic risk due to expanding into operational fisheries, but this step should not be taken unless the data from Stages 1-3 confirms that the risk of increasing capture rate has been robustly estimated to be negligible and the predicted benefits outweigh the costs. The design and analysis of such research should include international experts experienced in working with DDDs and fisheries issues.

4. RESEARCH CONCLUSIONS AND RECOMMENDATIONS

The final component of this project is to propose recommendations for future research on the use of DDDs in the New Zealand inshore fishery with respect to bycatch mitigation of Hector's and Māui dolphins.

In summary, the conclusions of the review about DDDs and Hector's and Māui dolphin bycatch mitigation are:

- While achieving variable success rates across marine mammal species, there have been some significant examples of large reductions in bycatch
- There have been some DDD trials with Hector's and Māui dolphins in New Zealand, but these have led to equivocal results but with some indication that Hector's dolphins avoid active DDDs
- DDDs appear most successful for cetaceans that are neophobic (i.e. fear of anything new) or are easily startled and have large home-ranges. They are, therefore, more likely to be more effective for phocoenids (i.e. porpoises) than coastal delphinids such as Hector's and Māui dolphins. As such, DDDs are less likely to be effective mitigation techniques for Hector's and Māui dolphins but the possibility exists that they could. The efficacy of DDDs will not be possible to assess without formal trials.
- Prior to any possible trials, the effectiveness of DDDs must be evaluated against two key considerations:
    - What reductions in bycatch may be achievable, and is this likely to meet management goals?
    - What sample sizes would be necessary in order to yield sufficient statistical power to quantify effectiveness?
- If DDDs are implemented, dedicated enforcement and compliance monitoring regimes will be required, as well as high levels of observer coverage to assess long-term effectiveness
- It is also important to note that while the focus of this review has been on mitigating impacts of commercial fisheries, any effective mitigation option should also be applied to non-commercial fisheries wherever possible.

Based on this review, it is clear that the potential exists that DDDs could be an effective form of mitigation of Hector's and Māui dolphin bycatch in New Zealand fisheries. Therefore, it is recommended that a staged approach to research is undertaken (as outlined in Section 3 above) and Stage 1 and 2 trials should be undertaken as these trials pose no risk to dolphins and are likely to provide useful data to aid in the evaluation of the efficacy of DDDs for the mitigation of Hector's and Māui dolphin bycatch.

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7. APPENDICES

Appendix 1. Summary of results of DDD literature review

Appendix 1 provides a summary of the results from the literature review. A short summary of all the papers and reports considered are show in Appendix 2 and the full version of the summary spreadsheet is available from the Department of Conservation (DOC).

A1.1. Literature review methods

A1.1.1. Collation and analysis of DDD literature

The review of existing literature on DDDs covered the following source material: international scientific literature, government agency commissioned reports, conference proceedings, commercial research and results from industry and scientific trials. In this field of research, there is also a considerable body of grey literature that is difficult to source but which is a large and valuable source of relevant information in this area. Electronic search engines and databases were used including: Web of Science, Current Contents, Google Scholar, and general internet searches, using keywords such as: dissuasive, deterrent (e.g. DDDs), gillnet, set-net, trawl, mitigation, bycatch, acoustic harassment devices (e.g. AHDs), and pinger.

The results from the review of each reference were summarised in an Excel spreadsheet allowing fully searchable access to the records. Individual references were evaluated and reviewed against the following criteria:

1. level of scientific rigor
2. level of proven efficacy
3. region and gear type
4. caveats and uncertainties in methods
5. relevance to NZ inshore fishery methods by gear type
6. relevance to Māui and Hector's dolphins
7. costs and benefits.

All of these criteria were then used to identify the papers and reports which appeared to be the most promising for understanding the potential mitigation potential of DDDs and also in designing trials to demonstrate DDD efficacy.

A1.1.2. Māui and Hectors dolphin bycatch in set-net and trawl fisheries

Analysis of existing New Zealand fishery data was undertaken using set-net and trawl bycatch summaries collated on the Protected Species Bycatch website from data held by Fisheries New Zealand (FNZ; Abraham et al. 2016). These include fisheries effort data compiled by FNZ in the commercial fisheries (WAREHOU) database from Catch Effort forms filled out by commercial fishers.

Data from government observers on fishing vessels from 2003 to 2018 was used to assess bycatch rates in both set-net and trawl fisheries as it represents the most robust data set available, although levels of coverage in some fisheries and / or areas can be low. Data was shown by gear (e.g. set-net, inshore trawl) across all fisheries and areas and provide an overall value reported by fishing year (e.g. October 1st to September 30th, the latter year is used to label the period).

Modelled bycatch estimates from a spatial risk assessment (Roberts et al. 2019) are also available by species and gear for the entirety of the effort (i.e. not just the observed component). Upon request, the authors provided us with a summary of their model estimates, and these were included in the report as time-series of mean predicted observed mortality by fishing year.

The following data were summarised:

- observed annual capture rates
- observed effort (e.g. km of set-net, number of inshore trawls)
- % annual observer coverage
- mean predicted mortalities per fishing year.

These data were used to investigate and characterise important features of the fishery that were used in the development of trials (e.g. observer coverage, Hector's and Māui dolphin bycatch rate)

A1.1.3. Existing DDD use in New Zealand

Information on the use of DDDs in New Zealand was collated from web searches and discussions with fishers, fishing representatives and technical experts involved in relevant research within New Zealand. These data were used to investigate and characterise important features of the fishery that were used in the development of trials (e.g. DDD models used, nature and extent of the existing use of DDDs).

A1.2. Literature review results

A1.2.1. Summary results

Forty-three papers and reports relevant to DDDs were identified. Most were published scientific reports (77%) or government reports (16%). Other types of literature included reports from international governmental agencies (2%), non-governmental agencies (2%) or conference proceedings (2%; Figure A1.1). All documents were deemed relevant in understanding and characterising the issues associated with

DDDs. A summary of these specific publications and the nature of the information contained within each is provided in Appendix 3 and within an electronic version of the full database available from CSP[3]. The publications and reports reviewed spanned the period of 1998 to 2019 with a majority undertaken between 2008 and 2014 (Figure A1.2).

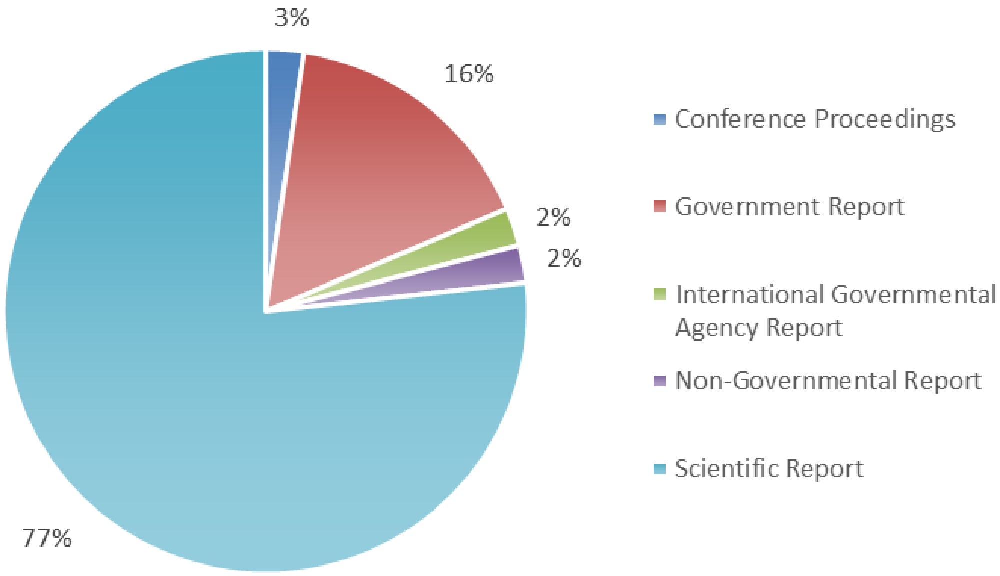

Figure A1.1. Proportion (%) of publications and reports by source (n=43).

[3] Database available from csp@doc.govt.nz

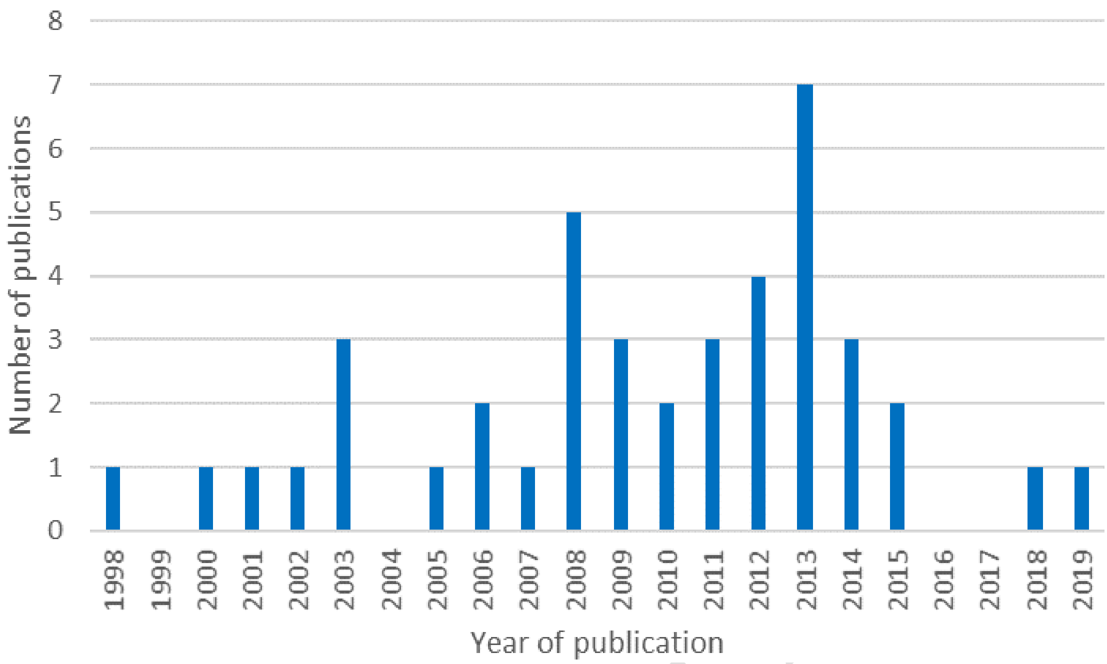

Figure A1.2 A breakdown of the number of publications and reports by year (n=43).

A1.2.2. Level of scientific rigor

Of the 43 references reviewed, 10 were reviews or other references that did not include an element of scientific testing. The remaining 33 references had the following levels of scientific rigor:

- high level 3% (n = 1)
- moderate to high level 3% (n = 1)
- moderate level 21% (n = 7)
- low to moderate level 42% (n = 14)
- low level 30% (n = 10).

While the assessment of these values is subjective to a degree, they do provide a high-level overview of a references' scientific rigor. This assessment is important in providing context to the results and how useful and accurate they are likely to be. For example, a significant result from a study with a high degree of scientific rigor is likely to be more robust (and useful) than one from a study with a low level of scientific rigor.

A1.2.3. Level of proven efficacy

There are many ways to measure efficiency of DDDs. The two main areas examined corresponded to a direct reduction in bycatch levels and any change in target fish catch. Of the 14 references with relevant data and which also assessed a change in bycatch levels, 86% (n = 12) demonstrated a significant decrease in bycatch levels.

The mean reduction in capture rates was 74% (SE = 6.2). Of the 13 references with relevant data to assess a change in target fish catch levels, 92% (n = 12) demonstrated no change to target fish catch levels. There were ten references that demonstrated both a decrease in bycatch levels and no change in target fish catch levels. When taking into account the scientific rigor of these ten studies, four had a low level, three had a low to moderate level, and three had a moderate level of scientific rigor. It is also important to note that while these studies found positive results, some had significant caveats or uncertainties associated with their work, which makes the determination of whether a result was actually robust to the caveats challenging. For a list of caveats and uncertainties identified in the literature, please see Appendix 1, Section A1.2.5.

A1.2.4. Region and gear type tested

There was broad geographic range for the studies undertaken with most research undertaken in the United States (n = 8), Denmark (n = 5) and the United Kingdom (n = 3), but with some research undertaken in New Zealand (n = 2) and Australia (n = 2). Most of the literature was focused on set-net or gill-net fisheries 72% (n = 31) plus some had more than one target fishery (e.g. set-net and trawl; 7% n = 3). Most of the references considered a wide variety of different types of set-net and / or gill-net operations including drift gill-nets, demersal gill-nets, artisanal gill-nets, static gill-nets and sink gill-nets. While all these methods are broadly similar, the differences between them need to be consider when assessing their likely utility for New Zealand fisheries. The remaining references covered a range of fishery methods including hand lining, shark control nets, trawl nets, long lines, and marine aquaculture farms.

Almost three-quarters of the references were related to set-net or gill-net fisheries. While most of these studies will have some relevance to New Zealand fisheries, there can be some significant differences between the set up and operation of these overseas operations to New Zealand operations. These differences notwithstanding, several of the lessons and learnings from these operations can be applied to New Zealand. Most important, is to be able to identify the mechanism by which improvements in bycatch were made so these lessons may be applied to New Zealand operations.

A1.2.5. Caveats and uncertainties in methods

Given the wide breath and scope of the literature as well as the inherent challenges in undertaking full randomised and experiments with appropriate controls, it is no surprise that a range of caveats and limitations were identified. The key message is that all of these issues need to be considered in the development of any future trials. While they do not necessarily invalidate the results found in all cases, they do make it more difficult to provide definitive conclusions to inform decision-making.

The caveats and uncertainties identified in each reference are identified in the full table of results (Appendix 3) by individual reference. Some of the key issues listed below:

- inadequate description of methods and results
- small sample sizes
- small effect size meaning that unrealistically large sample sizes would have been required to detect a statistically meaningful result (e.g. low statistical power)
- lack of a control in studies
- lack of a consistent application of an experimental approach including random elements to design
- non-representative sampling of unrealistic situations (e.g. testing not undertaken on working fisheries, observer coverage not random or representative)
- low levels of observer coverage during sampling
- lack of independent monitoring
- inappropriate pooling of results
- lack of testing of seasonal and / or different behavioural states (e.g. breeding, migratory, feeding)
- confounding of the impacts of multiple management measures (e.g. implementing DDDs, closed areas and seasons at the same time) and attributing all benefits to DDDs
- no investigation of longer term effects such as habituation
- sampling did not occur across a range of different densities of marine mammal locations so results may not be transferable.

A1.2.6. Relevance to Māui and Hector's dolphins

There was a wide range of different marine mammal species that were the focus of the DDD reports. The most common species was harbour porpoises, which were the subject of 30% (n = 30) of the literature with bottlenose dolphins (21%, n = 20) being the second most common species, and Hector's dolphins accounting for 5% (n = 2) (Figure A1.3).

While Māui and Hector's dolphins are taxonomically distinct from most other dolphin species (outside the *Cephalorhychus* genus at least), harbour porpoises could be considered as a useful proxy for them given the similarities in their acoustic capabilities (i.e. high frequency species). However, Dawson et al. (2013) investigated DDD studies and concluded that DDDs are more likely to be effective for neophobic (i.e. fear of anything new) or easily startled species (such as harbour porpoises) and likely to be less effective for species showing very flexible behaviour, coastal distribution, and high site fidelity (such as bottlenose dolphins). Māui and Hector's dolphins are very neophilic (i.e. attraction to new things) and may respond quite differently to DDDs than harbour porpoises. Therefore, any conclusions from harbour porpoise studies cannot be assumed to be directly relevant to Hector's dolphins. Regardless, results from these studies do highlight that DDDs can be effective for bycatch mitigation for some species and provide some useful background that can be used to explore potential mechanisms for deterrence in Māui and Hector's dolphins.

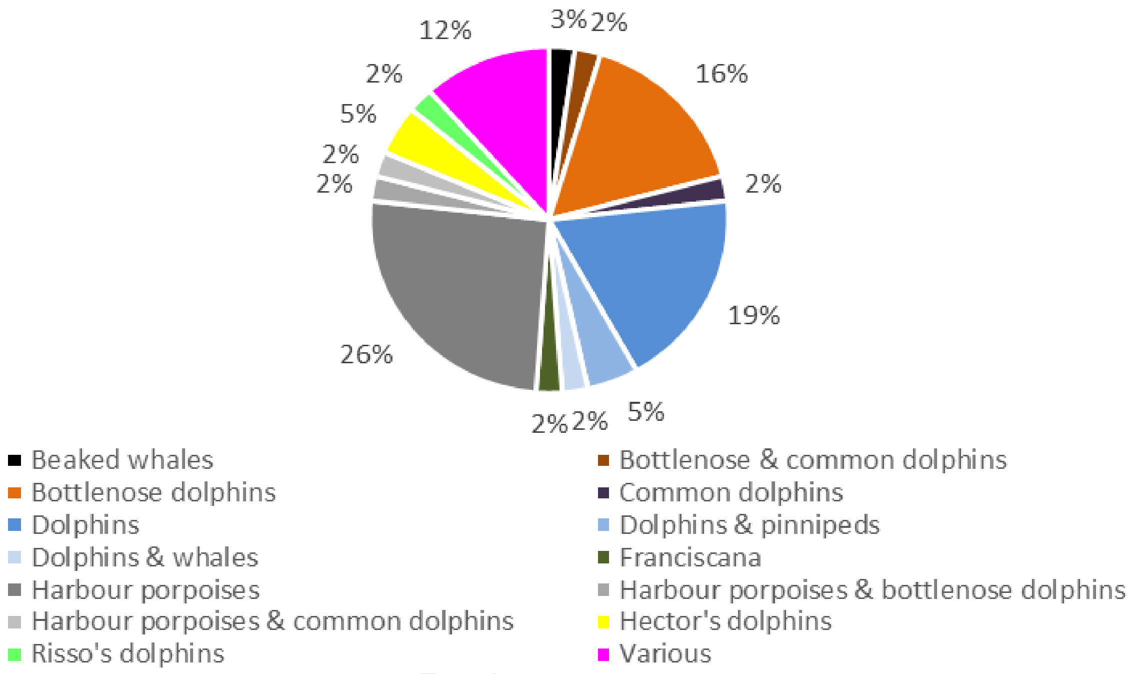

Figure A1.3 Marine mammal target species of publications and reports (n = 43).

A1.2.7. Estimated project costs

An important consideration in any scientific study is cost. We assessed the cost of DDD studies in the literature reviewed using relatively simple estimates (e.g. number of field days, number of observer days, number of pingers) as there were very few reports of the actual costs associated with the studies. There were some significant limitations to this approach as some studies were simple review articles, some studies only used pre-existing data whereas others were fully designed and implemented experiments in operational fisheries. Nevertheless, there is some utility in exploring these costings to provide an idea of the range of costings.

Estimated costings ranged from <$10,000 to projects in excess of $1 million (Figure A1.4). Almost 20% of all studies had budgets that were estimated to be in excess of $1 million and which generally reflected well-designed studies that were undertaken across an entire fishery using government and / or independent observers as the primary method for data collection. There were some small-scale field experiments that were undertaken for less than $100,000 which provided useful data but were generally limited in their applicability due to small sample sizes (e.g. small numbers of DDDs and /or limited field effort).

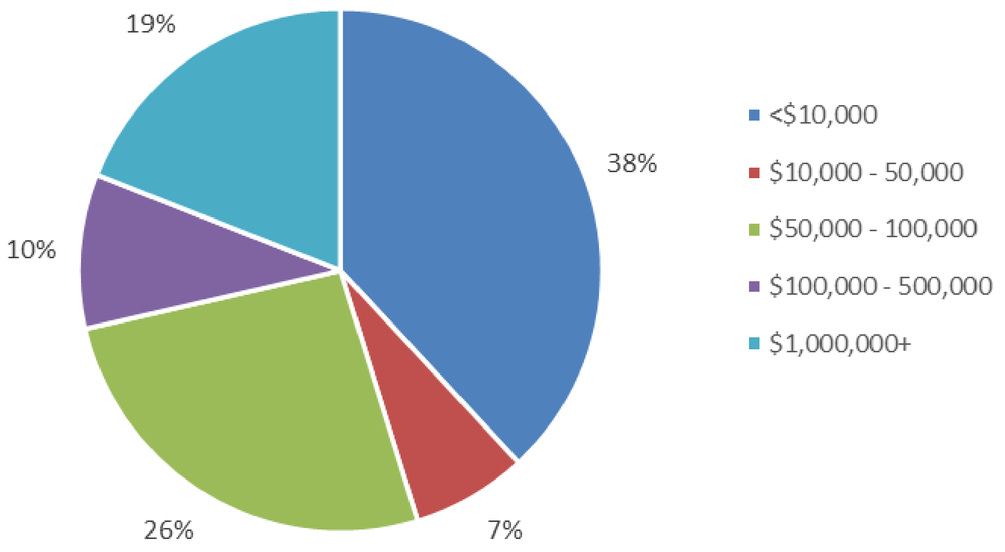

Figure A1.4 Summary of estimated costing of DDD trials in publications and reports (n = 42). Note that few of the papers and reports provided estimated of the cost of the project and so these are broad estimates based on studies which did provide some information.

Appendix 2. Issues relevant to the design and implementation of field trials

As per the contract requirements, we discuss in detail several issues specific to DDDs testing and / or bycatch of Hector's and Māui dolphins that need to be fully considered prior to designing any methodologies for possible field trials. These issues are discussed in order below with summary boxes provided for each issue.

A2.1. Hector's dolphin encounter rates

Encounter rate can be considered in two different ways: (i) the rate that dolphins are actually caught in fisheries or (ii) the rate that live dolphins may be encountered by fisheries or research vessels (e.g. live interaction rate). Both types of rates are important to consider when developing field trials, but they must be estimated and considered separately. Obviously, if all the dolphins that encountered a fishing activity were caught then these two values would be equal, but this is unlikely to be the case in most fisheries. Māui dolphins were not considered as their encounter rates are so low as to make any robust statistical trial virtually impossible.

A2.1.1. Encounter rate – catch

Based on an analysis provided in Section 2.2, HDs appear to have a low capture rate in commercial fisheries By contrast, one of the few studies that was rated high for scientific integrity in our literature review (Mangel et al. 2013) had an estimate of annual fleet wide captures over 100 times higher than the comparable estimate for New Zealand and the comparable catch rate is 67 times higher.

These very low encounter rates make it logistically very problematic to design a robust experiment from fishing vessels that can detect the impact of DDDs on capture rates. This difficulty is simply a reflection of the existing rate of observed encounters being so low that the observed fishing effort would have to be extremely high in order to detect a statistical difference. For example, if DDDs were fully effective and a dolphin was never captured, it would still take many years before additional zero captures in the time-series could be statistically attributed to the impact of DDDs. If there is only one year or two with zero captures, it might just be a random effect.

A statistical power analysis could normally tell us the number of sets that would have to be observed to detect a decline in capture rates under treatment. However, as these data are not normally distributed (most of the observations are zeroes), a traditional statistical power analysis (i.e. one where the required sample size is calculated directly as a function of effect size, dispersion and the desired rate of Type II error), would not give reliable results. A more robust approach would be to simulate captures from a negative binomial error distribution that mimics the properties of observed captures (e.g. high number of zeroes, occasional one or two captures). However, for this to provide useful insights to inform an experimental design, other factors would have to be taken into account, such as the distribution of fishing effort compared to Māui and Hector's dolphin habitat, and seasonal patterns in occupancy. This analysis has not been undertaken as part of this project given the scope of the contract and the complexity of the task although a detailed assessment of Hector's and Māui dolphin capture rate and fishery behaviour has been undertaken by Roberts et al. (2019) as part of the Hector's and Māui dolphin TMP process and would serve as a useful starting point.

Conclusion: The capture rate for Māui and Hector's dolphins is low compared with many overseas fisheries, which will make any statistically robust estimation of improvements from DDDs challenging. This is not to say that genuine improvements in capture rate cannot be measured, but that it will be difficult to do so in the short term (e.g. < 2-3 years). Instead, it is likely to require a large sample size (e.g. much higher level of observer or electronic monitoring than currently) collected over multiple years. It is highly unlikely that any statistically meaningful result could be achieved for Māui dolphins given the extremely low capture rate and extremely low number of individuals remaining in the population. Discussion of specific areas in which encounter rates are likely to be high is provided in Section 0.

A2.1.2.`Encounter rate – density

The best available estimates of dolphin density (i.e. a reasonable proxy for occurrence) is the modelling of aerial survey data provided in MacKenzie and Clement (2014; Figure A2.1) and Roberts et al. (2019; Figure A2.2). These data highlight areas with the highest relative dolphin density and therefore those locations with the highest occurrence of dolphins.

Conclusion: The best place to undertake a DDD experiment would be where dolphin densities are likely to be the consistently high throughout the year which is around Banks Peninsula and further south towards Timaru.

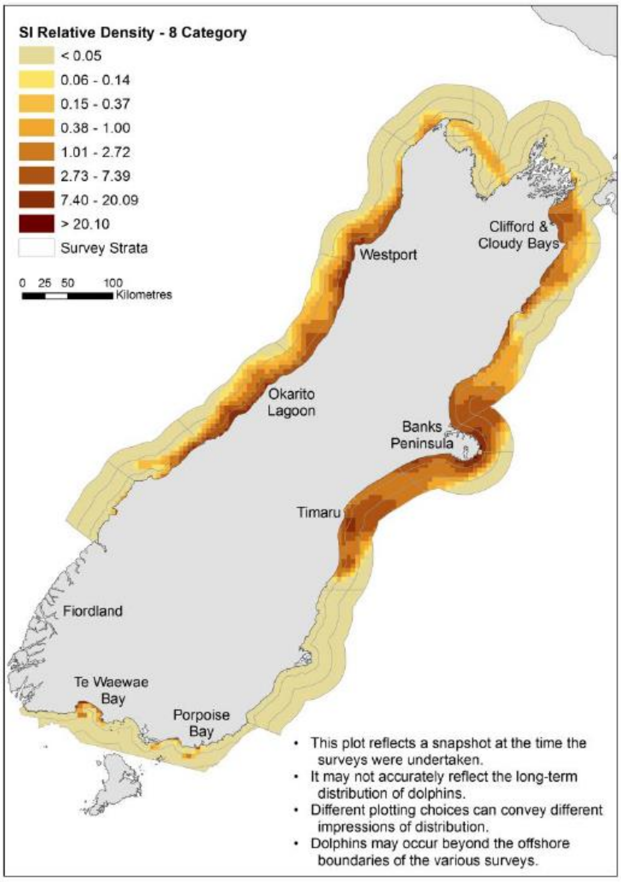

Figure A2.1. Relative density of Hector's dolphin rates within 5 km x 5 km grid cells generated from Density Surface Models of aerial survey data. Reproduced from MacKenzie & Clement (2016).

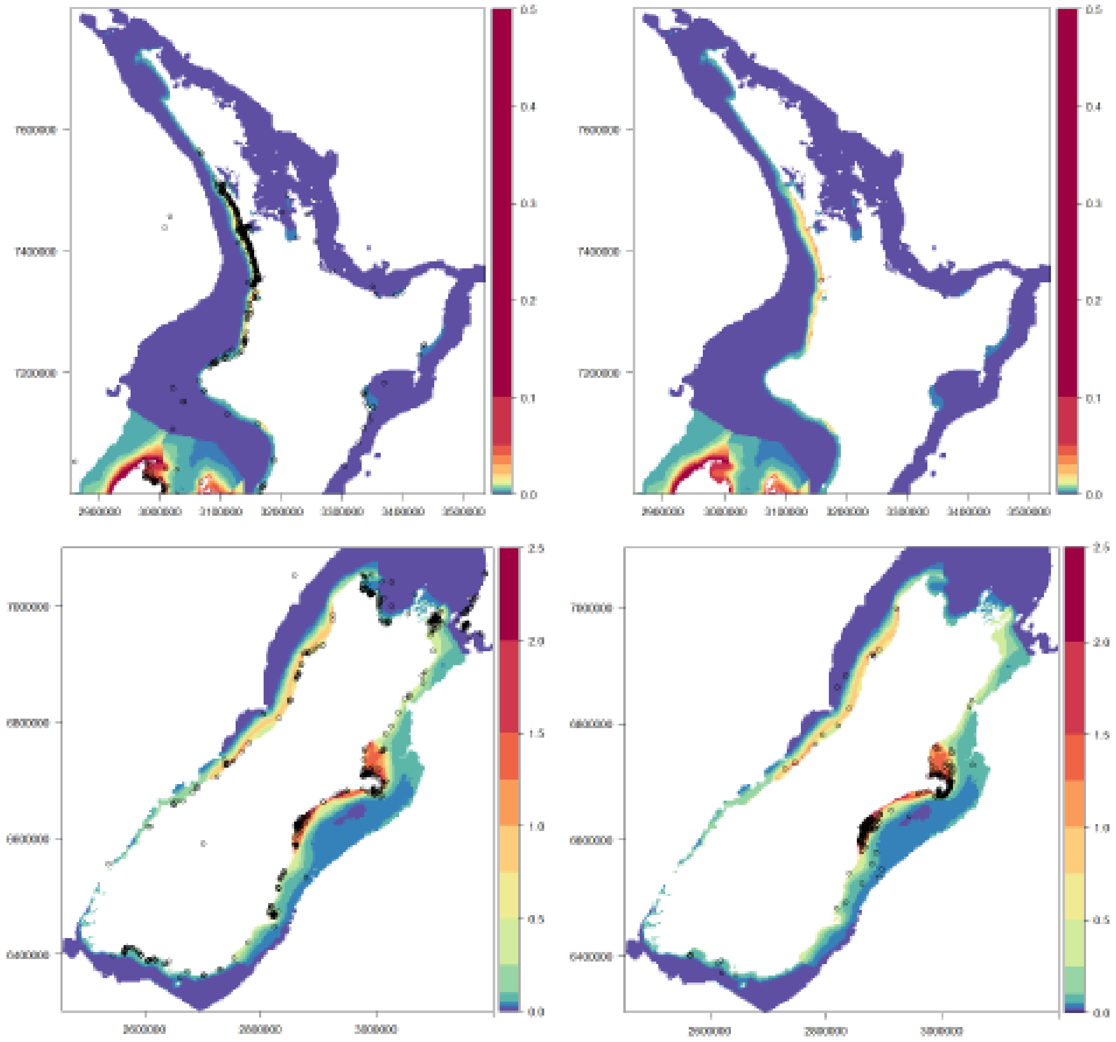

Figure A2.2. Final predicted spatial density of Hector's and Māui dolphins in summer used for spatial risk assessment compared with the spatial distribution of public (left) and commercial fishery observer summer sightings (right). Figure 25 reproduced from Roberts et al. (2019).

A2.2. Identification of sampling sites to maximise results from a trial

The identification of sampling sites will be driven by the specific research question and locations should be chosen so that the power of any trial is maximised. Choices will include selecting areas where a combination of dolphin density and fishing effort are both considered and must also include consideration of other factors such as the ease in achieving adequate monitoring (e.g. observer programme or electronic monitoring).

There is a useful exploration of the spatial overlap and interaction of fisheries with this species in Roberts et al. (2019). One of the key findings was that areas of elevated risk from fishing were identified on the east coast of the South Island (e.g. along the

Kaikoura coast, immediately to the north of Banks Peninsula and in the South Canterbury Bight (Roberts et al. (2019); Figure A2.3). These are potentially useful sites for trials as they are where dolphin-fishery interactions are likely to be high and therefore empirical data may more easily be collected.

The draft Māui and Hector's dolphin Threat Management Plan (TMP) is presently with the government for consideration with a range of options proposed, potentially including large increases in areas closed to fishing. While the government has yet to release its decision, it is possible that additional areas will be closed to fishing. Without this knowledge, the development of any large-scale trial could be compromised or wasted due to future fishery restrictions.

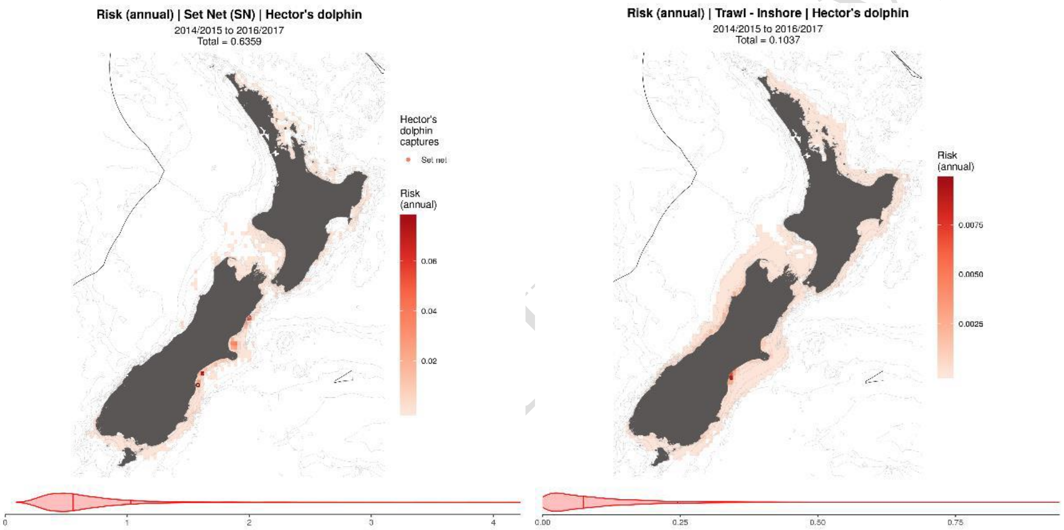

Figure A2.3. Total annual risk ratio (the mean from 2014/15 to 2016/17) for commercial set net and trawl fisheries with Hector's dolphins. Observed Hector's dolphin captures in set nets between 2014/15 and 2016/17 are also shown as red points. The posterior distribution of the risk ratio is also displayed as the violin along the bottom with the median and upper 90% quantile indicated by the vertical lines within the violin. Figure A15-7 reproduced from Roberts et al. (2019).

Conclusion: To maximise the amount of data that can be collected to investigate the effectiveness of DDDs a study needs (i) high number of dolphins and (iii) a high degree of overlap with fisheries. As noted in Roberts et al. (2019), the highest interaction rate is around the Bank Peninsula region, potentially as far north as Kaikoura and as far south as Timaru.

A2.3. Development of appropriate metric of dolphin deterrence for reporting

A robust experiment would need to measure a response variable and assess whether there is a statistical change in that response variable in the presence of DDDs. There are wide range of potential response variables to consider including the following:

1. Capture rates: Capture rates can be measured as the ratio of the number of captures (dead and / or alive) to the fishing effort observed.
2. Local abundance and / or density
3. Sightings: Sightings are simply a measure of number of dolphin sightings in an area and could be collected from methods such as line transect surveys (e.g. aerial or boat), fisheries observer observations or even from land-based observations
4. Vocalisations: Vocalisation rates can be assessed using a hydrophone placed underwater measuring relative changes in acoustic vocalisation rates as an index of dolphin presence
5. Behaviour: Behaviour can be measured in many different ways including behavioural budgets, dive behaviour and habitat use.
6. Demographics: Variables such as survival rates or recruitment rates could be estimated to show change.

These potential metrics vary between direct (e.g. capture rate) and indirect (e.g. abundance, vocalisations) measures of an effect of DDDs. Care must be exerted with indirect measures especially where it may be impossible to link any change seen in the metric (e.g. abundance or vocalisation rate) to a change made to the fishery, since the change in metric could be driven by a range of factors. For example, it could be that DDDs significantly lower dolphin vocalisation rates within their vicinity, but they may not actually lower capture rates if the dolphins are still utilising the local environment in the same way. Making inference from such an effect (without understand this effect) would provide false positive support for the potential effectiveness of DDDs. Linking any changes to actual DDD effects is thus imperative if a real benefit from DDDs is to be demonstrated

Also, the appropriate variable to measure in an experiment will change depending on the inferred mechanism via which DDDs are thought to act. If DDDs are thought to decrease local abundance around fishing gear, then changes in capture rates or local abundance can both be used as a response variable. If DDDs are thought to act by allowing Hector's and Māui dolphins to detect and avoid the net, than change in capture rates can be used as a response variable, but not local abundance as it should not be impacted by the presence of DDDs. In this situation, a change in behaviour would be the ideal response variable to measure as it is the direct result of the DDD's presence (under this model).

Capture rates are potentially the easiest and cheapest response variable to monitor assuming that capture events are recorded reliably. However, as discussed in Section 2.2, the low encounter rates of Hector's and Māui dolphins with fishing gear make it impractical to rely solely on this variable to assess the effectiveness of DDDs. While an option could be to concentrate fishing effort in areas of higher Hector's and Māui dolphin densities, it is unlikely to be desirable to increase capture rates for experimental purposes due to the increased risk it would pose to the Hector's and Māui dolphin populations in the event that DDDs do not work (see additional discussion in Appendix 2, Section A2.5).

Ultimately direct metrics such as bycatch rates will always be preferred over indirect metrics for the simple reason that they actually measure the variable of interest. However, indirect metrics may be useful for preliminary trials to investigate the effectiveness of DDDs before moving to full fishery trials or are collected alongside direct measures to provide supporting information.

Conclusion: The best metric to measure the efficacy of DDDs is change in capture rate for the simple reason that it is the end goal. However, while changes in capture rates have been measured effectively overseas, this is likely to present a range of challenges for New Zealand fisheries including a relatively low capture rate and difficulties with achieving high levels of observer coverage due to challenges placing observers on small inshore vessels[4]. Both these issues are going to make it extremely difficult to estimate baseline levels of bycatch rates accurately and robustly. Therefore, measuring any change (positive or negative) will also be difficult. Nevertheless, monitoring capture rate should be the ultimate goal for demonstrating the efficacy of DDDs. However, other metrics (e.g. vocalisation rates, habitat usage) may be suitable for assessing the effectiveness of DDDs during preliminary trials prior to full fishery experiments. Ideally, a combination of metrics would be used following a weight of evidence approach to provide a broad assessment across a range of variables.

A2.4. DDDs used in literature and presently available

There is a description of most of the DDDs that appear in the literature provided in the summary spreadsheet available in the full electronic database available from CSP[5]. There is a huge variation in the type, construction, frequency range, pulse interval and battery life between all the DDDs covered. Many of these models, such as the Dukane NetMark 1000—most reported DDD in the literature, are no longer commercially

[4] although this latter issue potentially could be resolved with the introduction of an effective and robust electronic monitoring programme

[5] Database available from csp@doc.govt.nz

available and some were only experimental models and have never been made available.

The only published study that has tested DDDs in New Zealand and with Hector's dolphins is Stone et al. (2000) which used PICE (Black) and DUKANE (Red & White) DDDs, but these models are no longer commercially available. The only DDDs currently commercially available for purchase in New Zealand are STM (Italy) products including the DiD-01, DDD-03H/U and DDD-03L, which are sold by Marintec Limited in Timaru. There are wide range of different DDDs available around the world including from FishTek Marine[6] (UK), Future Oceans[7] (USA), ETEC[8] (Germany) and AQUATECH[9] (UK) that can also be purchased for use in New Zealand.

The features of an effective DDD can be summarised from the investigation of the references considered 'successful studies' in our review and summarised in Table 1. While these features are likely to be specific to the fishery and bycatch species for which they are aimed at reducing captures, there may be some useful characteristics than can be applied more widely. These characteristics include:

- DDD models: Dukane NetMark 1000 (3 studies), Aquatec AQUAmark 210 (1 study), and SaveWave White & Black (1 study)
- Frequency ranges: 5-160 kHz or 10-12 kHz
- Decibel level: 132, 135 and 155 dB RMS re: 1 µPa
- Continuous pulses including a random selection of variable frequencies (e.g. to ensure that dolphins do not habituated to a single repetitive pulse)
- Pulse rate: ~4 seconds
- Pulse length: ~300 milliseconds
- Battery life: highly variable between DDDs but generally in the order of 40-100 hours before requiring a recharge. Obviously, this would need to cover the entire soak time (including longer than expected soaks if the gear cannot be covered on schedule)[10].

Conclusions: As discussed in the Section 0, the only DDDs presently in use by commercial fishers in New Zealand are made by STM (e.g. model DDD-03) and are therefore the obvious model of DDDs to test in the first instance. They also meet all the characteristics identified above including a pulse frequency range of 5-500 kHz which covers the full spectrum of Hector's and Māui dolphin vocalisations (and presumably also their audibility range).

[6] See https://www.fishtekmarine.com/deterrent-pingers/
[7] See https://www.futureoceans.com/pingers/
[8] See https://www.etec.dk
[9] See http://www.aquatecgroup.com/11-products/25-aquamark-840
[10] An additional important factor is unit recharge times which can vary between 8-20+ hours and so consideration needs to be given to having enough units charged and available to cover units with longer recharge times.

A2.5. Social science considerations

Māui and Hector's dolphins have an extremely high public profile in New Zealand and are routinely the subject of media attention. There are various stakeholder groups that regularly use Māui and Hector's dolphins in advertising campaigns raising the profile further. In addition, Māui and Hector's dolphins are taonga species for many iwi, hapu and other New Zealanders. They are also formally listed in the Ngai Tahu Deed of Settlement.

Social science considerations are important with any research but are particularly relevant to studies that involve potential injury or mortality of animals. While the public would welcome any new effective mitigation options, they are likely to be fundamentally opposed to any experiment in which bycatch rates may increase. There is evidence from some DDD studies that bycatch rates have increased apparently because of DDD malfunctions, inadequate DDD spacing and numbers, or even the attraction of other marine mammal species such as sea lions (Bordino et al. 2002).

While there is already an existing bycatch issue with Hector's and Māui dolphins, there needs to be careful consideration of any experimental study so that there is no chance that capture rates are increased by the experiment. While this may not be possible to guarantee, it does support the strong need for a structured and staged approach to any testing. A staged approach could take the form of preliminary experiments outside of a fishery to demonstrate potential benefits without the risk of additional mortality. Such a staged approach could begin with research on issues such as: (i) measuring the reliability (e.g. how well the survive being used in a commercial fishery) of DDDs, (ii) assessing battery life, (ii) confirming pulse frequencies, decibel levels and effective detection distance (to determine adequate line spacing), (iii) can they be deployed / retrieved easily by fishers on all fishing systems and / or (iv) systematically describing dolphin behaviour around active DDDs. Any trials or experiments are likely to require permits (e.g. Marine Mammal Research Permit) and approvals (e.g. Animal Ethics) of which public input is a key component and therefore a social license to operate will be essential.

Conclusion: Careful consideration of the potential implications from any DDD trials will be necessary to ensure stakeholders, the public and iwi are all aware of the proposals and implications. Given the potential for possible increases in capture rates from an unsuccessful trial, it underpins the strong need for a structured and staged approach to any testing with a thorough consideration of risks prior to any trial in a real world fishery situation. Finally, there will need to be a media and consultation plan in place to support any trials although the existing DOC CSP and / or FNZ AWEG process would be appropriate processes to consult about any trials.

A2.6. Elements of best practice methods

There were some common themes to the studies which had a moderate or high degree of scientific rigor. In essence, these are the polar opposites of the caveats and biases that were identified in the poor studies as outlined in Appendix 1, Section A1.2.5.

Some of the best practice approaches from the scientifically rigorous studies include the following components:

- strong experimental design including use of appropriate controls and double blind experiments
- use of independent government observers and / or independent scientists to provide robust and accurate monitoring data
- large sample sizes (e.g. > 25% of all fishing effort)
- Consideration and monitoring of range of potential variables and fixing variables wherever possible
- formal necropsies of dead individuals for which cause of death was not able to be directly confirmed
- multi-year and multi-regional studies and consideration of issues such as habituation. In particular use of long term, existing, robust data sets to establish base line capture rates is particularly useful
- calculation of statistical power for results to aid in accurate interpretation of any significant (and non-significant) results
- concurrent monitoring of commercial fish catch as an essential part of the trial to demonstrate any impact on catch
- clear instructions and communication provided to all parties involved in the trials (e.g. fishers, observers, managers) to ensure experimental designs are implemented accurately (e.g. to ensure comparability between vessels, areas, and years) including appropriate training
- well-funded; most of the research that provided a robust fishery level result utilised existing government observer programmes that were estimated as exceeding US$1 million in value.

There are also some international DDDs standards that have been applied in different parts of the world and can be considered to be best practice for those fisheries and target species (i.e. harbour porpoises). The two most common DDDs standards are the EU standard (e.g. previously the EU standard 812/2004 that has now been replaced by EU standard 2016/0074[11] in 2019) and the US standard (e.g. as specified in the National Marine Fisheries Service (NMFS) Harbour Porpoise Take Reduction

[11] See https://eur-lex.europa.eu/procedure/EN/2016_74

Plan[12]). Both standards specify the requirements for the type, use and operation of DDDs that are required to be used in specific fisheries. While there is a considerable amount of high level detail that this only relevant to these fisheries, there is also some excellent descriptions of DDD specifications, which are broadly consistent with the DDD characteristics identified in Section 0.

Conclusion: The components of existing trials that are identified in the list above should form the basis on any trial in New Zealand although there will need to be careful consideration of some of the elements (e.g. available funding, development of a large scale and robust monitoring programme). The elements identified above generally relate to large scale trials in operational fisheries, but most could be equally well applied to smaller, preliminary trials prior to a large scale roll out at fishery level.

A2.7. Research costings

It is extremely difficult to provide reliable costings for DDD trials given the considerable variation in the scope, nature, and extent of a trial. However, it is possible to summarise what was found in the literature review which was discussed in Appendix 1, Section A1.2.7.

As a general rule, robust DDD studies that provide extensive coverage of a fishery are likely to be very expensive (e.g. NZD$100,000s to NZD$1,000,000+) due to the large sample sizes that are likely to be required to achieve robust, statistically significant results. In general, the majority of costs in such a study is related to the provision of monitoring through the use of independent observers.

For New Zealand, the approximate daily cost for a Government Observer is NZD$1,090 per day[13] so attempting to achieve high levels of observer coverage across multiple vessels is quickly going to run into thousands of dollars per day. While these costs can be high, they can be piggy-backed with existing projects. For example, the Conservation Services Programme Draft Annual Plan for 2020/21 states that there are 598 days (e.g. with a total value of NZD$652k) of observer effort proposed to cover South Island inshore set net effort for the 2020/21 fishing year. All of these days could be potentially be used in a trial of DDDs although it is important to note that: (i) this effort will be spread around the entire South Island so it would not all be available to cover a trial that only occurs in a single region and, (ii) while this number of days is estimated to achieve 25%, 35% and 65% coverage of three inshore set net fisheries, the highest level of coverage ever achieved in inshore set net fisheries has been 6% so these targets appear extremely optimistic.

[12] See https://www.fisheries.noaa.gov/new-england-mid-atlantic/marine-mammal-protection/harbor-porpoise-take-reduction-plan
[13] Cost based on the stated rate for observers working in inshore fisheries data provided in Table B of Appendix 1 of the Conservation Services Programme Draft Annual Plan 2020/21. May 2020

Notwithstanding these potential limitations, if these coverage levels could be achieved, then they could form the foundation for a reasonable monitoring programme for any trial of DDDs. Following an appropriate power analysis developed for a DDD trial, it would then be possible to estimate the additional number of observer days that would be required to deliver a robust study and funding for these days would have to sought. In an ideal world, achieving 100% observer coverage in these same three fisheries would require 1,857 days at total cost in excess of NZD$2 m for a single year.

While the focus here has been on monitoring using observer programmes, it may be possible to achieve the same level of scientific rigor from an electronic monitoring programme. If that were possible, then potentially costs could be significantly reduced for a monitoring programme.

Another significant cost for a trial would be the purchase of DDDs with a price of approximately NZD$400-600 per unit. While the number of DDDs required per 100m of net is likely to be species and fishery specific (and would require research to determine for Hector's and Māui dolphins), a reasonable rule of thumb is one DDD every 100-200 m of net. With individual set netters likely setting up to several thousand metres of net each day, between 100 and 400 DDDs could be required to provide full coverage of a net. Therefore, costs for purchasing enough DDDs to cover 1,000 m of net would be in the order of NZD$50k or $100k depending on DDD spacing. Depending on type of DDD, it may also be necessary to have additional units if the recharging time is greater than the time between sets. While these are one off costs as DDDs are reusable, it is a large up-front cost. One option might to design a trial that could work with New Zealand fishers who are already using DDDs so that purchasing them is not necessary.

Trial costs are likely to include vessel charter but again, these may have able to be negotiated with fishers interested in being involved in a trial. Charter costs could be significant if the experimental design requires a fishing vessel to change their normal fishing behaviour. Non-fishing vessels may also be used for trials depending on the nature of the trial being undertaken.

Most of the focus so far has been on large scale fishery trials but there is are also likely to be smaller, strictly experimental projects especially if a stage approach to research is used. Such smaller, more traditional research programmes are well represented in the literature review with costings ranging from low NZD$10,000 to NZD$500,000 depending on scale.

Any trial will require input from biologists, statisticians, modellers, and other technical people whose time will also have to be covered.

Conclusion: It is unhelpful to speculate about what a DDD trial may costs without know the structure of that trial. However, what is clear is that there are range of research projects that range in scale from small strictly experimental projects to large scale projects embedded in existing fisheries. Estimated costs for projects in the literature review ranged from <$10,000 to greater than $1 million. Almost 20% of all studies had budgets that were estimated to be in excess of $1 million and which generally reflected well designed studies that were undertaken across an entire fishery using Government and / or independent observers as the primary method for data collection. There were some small scale field experiments which were undertaken for less than $100,000 which provided useful data but were generally limited in their applicability due to small sample sizes (e.g. small numbers of DDDs and /or limited field effort). If a staged approach to research is undertaken, then the project could start off with modestly priced smaller studies and, based on positive results, progress through to larger, more expensive projects.

A2.8. Key issues to consider for the experimental design of DDD efficacy trials with Hector's and Māui dolphins

There is nothing particularly unusual about the experimental design required for a DDD trial in New Zealand that differs from any other robust scientific study. Some of the key elements already identified in the previous section will of course be highly relevant. However, it is critical to consider some of the key features of both Hector's and Māui dolphin biology, the fisheries, and what we know about the resulting interaction to develop a well targeted and robust trial.

Based on some of the previous findings in this report, the following issues need be considered when developing a robust experiment:

1. **The relatively low capture rate of both Hector's and Māui dolphins compared to most fisheries bycatch issues overseas**. This is especially true for Māui dolphin which makes it highly unlikely that it would be possible to develop a robust trial to confirm a positive effect. For Hector's dolphins this low capture rate will require a large sample size to robustly confirm any moderate to large effect and it is likely that the chance of detecting any small effect will be limited.
2. **Challenges with achieving high levels of robust monitoring**. Observer coverage in the inshore set net fishery has traditionally been very low (e.g. < 3%) although there are some promising signs that this is starting to increase (see Figure 3) with a maximum level of 6% achieved in 2018. However, there are some inherent challenges with the fishery that will make it difficult to provide reliable and robust coverage of the fishing fleet (e.g. small vessels with limited space for observers). Electronic monitoring offers a potential alternative to Observers.
3. **Hector's and Māui dolphins have complex spatial and temporal patterns**. While this is not unusual for a marine mammal species, it adds complexity to the

design of a robust trial requiring the experimental design to address potential seasonal and regional differences. This is not insurmountable as has been demonstrated in the recent spatial analysis presented in Roberts et al. (2019). This issue is also related to the issue identified in Item 5 below.

4. **A trial should be cost effective**. Any trial would need to be adequately funded to achieve its objectives. It is likely that any trial would be jointly funded by the fishers and the Crown, but the cost of the trial should not be unreasonably burdensome on fishers. Given that the total amount of fishery effort in the set net fishery has been steadily declining over time, the cost of paying for a trial will likely fall to fewer and fewer fishers. Unless the government is prepared to pick up a large component of the cost, then it is likely that the size of a trial will be constrained by the ability of fishers to contribute.
5. **Statistical power analysis**. As discussed in Section A2.1.1, a traditional power analysis is unlikely to provide reliable results, and therefore a more complex simulation based approach would be required to support the experimental design. Again, while this is not insurmountable, it adds to the complexity in the design.
6. **Staged experimental approach**. While it could be possible to design and launch into a fully comprehensive experiment, it may be useful to take a staged approach in a stepwise fashion. For example, simple trials could be first conducted outside of a fishery to test issues such as the actual mechanism for reducing capture rates (e.g. avoidance vs. awareness).
7. **Māui dolphins are critically endangered**. Given the critically endangered status of Māui dolphin, it would be unethical to undertake any trial where there was even a small possibility of an increase in capture rates. Considerable preliminary trial work would be required prior to any trial in a commercial fishery to provide confidence that capture rates will not increase. A single additional capture is unsustainable for this sub-species.
8. **Social license to operate**. As discussed in Section A2.5, Hector's and Māui dolphins are taonga species for many iwi, hapu and other New Zealanders. While all groups would welcome any new, effective mitigation options, they are likely to be fundamentally opposed to any experiment in which bycatch rates may have the potential to increase. While not strictly an experimental design issue, it is an important issue to consider when developing a trial.
9. **Uncertainty around the status of the Hector's and Māui dolphin Threat Management Plan (TMP)**. The draft Hector's and Māui dolphin TMP[14] is presently with the government for consideration with a range of options proposed, potentially including large increases in areas closed to fishing. While the government has yet to release its decision, it is possible that additional areas will be closed to fishing. Without this knowledge, the development of any large scale trial could be compromised or wasted due to future fishery restrictions.

[14] See https://www.doc.govt.nz/get-involved/have-your-say/all-consultations/2019/hectors-and-maui-dolphins-threat-management-plan-review/

All these issues will feed into the development of a DDD trial or even several different trials.

Conclusion: Consideration of the elements identified above coupled with the sources of uncertainty and bias identified in Section 0, will support the development of a robust experimental design to assess the efficacy of DDDs. Furthermore, there are some high quality studies identified in the literature review (e.g. Appendix 3) which can provide useful templates to guide the development of New Zealand studies. In addition, the design and analysis of such research should include international experts experienced in working with DDDs and fisheries issues.

A2.9. Summary

This section covers a wide range of issues that must be considered when developing and designing a set of experimental trials to test the efficacy of DDDs in mitigating Hector's and Māui dolphin bycatch. A summary of the issues and recommendations for potential future trials is presented in Sections 3 and 4 above.

Appendix 3. Complete list of reports and publications reviewed including short summaries of key findings.

Number	1
Reference	Alfaro Shigueto 2010
Year	2010
Study name	Experimental trial of acoustic alarms to reduce small cetacean bycatch by gillnets in Peru
Fishing gear	Gillnet
MM bycatch (test) species	Species caught: Dusky dolphin (*Lagenorhynchus obscurus*), bottlenose dolphin (*Tursiops truncatus*) and common dolphin (*Delphinus capensis*), and pilot whales.
Key finding	The results of the study suggest that pingers may indeed be effective at reducing the bycatch of small cetaceans - fishing sets that used pingers had at least a 73% reduced rate of capture of dolphins and porpoises in relation to control sets. Catch rates of the target species were unchanged.
Assumed causal agent for avoidance?	Not discussed
Level of scientific rigor (dark green = high rigor, dark red = low rigor)	Low - moderate: Controlled experiment testing. Small sample size, different control, and test vessels, over three seasons.
Caveats or uncertainties to methods	Controlled experiment testing. Small sample size, different control, and test vessels, over three seasons.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	Pingers may indeed be effective at reducing the bycatch of small cetaceans - fishing sets that used pingers had at least a 73% reduced rate of capture of dolphins and porpoises in relation to control sets. Catch rates of the target species were unchanged.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	cost of individual pingers (approximately $80US, or $800 to equip a 1km net). The UK based company Fishtek (fishtekmarine.com) is currently developing a pinger with an anticipated cost of £15-20. Such a device would go a long way to making pingers economically feasible in small scale fisheries. Requires MM deaths to be able to determine success.
Benefits	Able to be performed on existing fisheries.

Number	2
Reference	Baker and Hamilton 2014
Year	2014
Study name	Technical Review: Development and Application of Bycatch Mitigation Devices for Marine Mammals in Mid-Water Trawl Gear
Fishing gear	Various discussed, no nets used.
MM bycatch (test) species	Various
Key finding	Of the commercial gillnet pingers, only the DDD has shown some effect in pelagic fisheries. Pingers (DDDs) should be fully charged and deployed on the lower wing ends or bridles of the trawl to ensure they continue to function correctly. Although DDDs appear to be effective in reducing dolphin bycatch, there are still challenges to address including determining the most effective configuration for mid-water trawls. Deployment of pingers may interfere with normal fishing operations, and French fishermen prefer to use a softer pinger set on the rear part of the trawl rather than use a DDD set on the wings of the trawls because there is less interference with the netsonde.
Assumed causal agent for avoidance?	Not discussed
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	NA
Caveats or uncertainties to methods	Not many papers reviewed
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Of the commercial gillnet pingers, only the DDD has shown some effect in pelagic fisheries
Application to NZ inshore fisheries	Lists issues with pingers
Relevance to protected dolphin species assemblages in NZ	Issues listed are useful for developing test methods in NZ
Costs	Low costs for a literature review. Pingers are commercially available from a number of suppliers and are marketed under various trade names
Benefits	Indicative summary of pinger use.

Number	3
Reference	Barlow and Cameron 2003
Year	2003
Study name	Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery
Fishing gear	Drift gillnet
MM bycatch (test) species	Various cetacean and pinnipeds
Key finding	Pingers significantly reduced total cetacean and pinniped entanglement in drift gill nets without significantly affecting swordfish or shark catch, results also indicate a greater reduction with a greater number of pingers. For species tested separately with this test, bycatch reduction was statistically significant for short beaked common dolphins (P 0.001) and California sea lions (P 0.02). Bycatch reduction is not statistically significant for the other species tested separately, but sample sizes and statistical power were low, and bycatch rates were lower in pingered nets for six of the eight other cetacean and pinniped species. For a net with 40 pingers, the models predict approximately a 12- fold decrease in entanglement for short-beaked common dolphins, a 4-fold decrease for other cetaceans, and a 3-fold decrease for pinnipeds
Assumed causal agent for avoidance?	-Could not tell whether the observed pinger effect was caused by the sound produced by the pingers or by the presence of something novel hanging from the net. We believe that the visual enhancement caused by the presence of the pingers at night is trivial and that the sounds they emit almost certainly caused the reduction in bycatch; however, our design does not allow us to distinguish between these hypotheses. '-Given the relatively small number of nets and the huge area fished, habituation may be less of a concern for the California drift gill net fishery than for intensive, localized set gill net fisheries in the Gulf of Maine and in the North Sea. We believe that pingers are unlikely to reduce the bycatch of all cetacean species or all pinniped species.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Moderate: moderate sample size, missing some information about vessels, only over a single year, good statistics, not all variables able to be controlled, but only robust data included in the analysis. Includes pinnipeds and cetaceans in the same experiment, uses real fisheries examples
Caveats or uncertainties to methods	-"An impractically large sample would be required to find a statistically significant result for rare species, even if their response was the same as for common dolphins." '-The actual number and configuration of pingers varied due to differences in net length, pinger failures, and other uncontrolled factors. '- Experimental protocols were not followed on every set. Sometimes skippers chose not to employ pingers in rough seas (18 cases), during the first set of a season or the first set with an inexperienced crew (7 cases), when pingers were causing problems (2 cases), or for other reasons (20 cases). Occasionally, skippers chose to employ pingers even when the protocol called for none (because marine mammals were known to be present, 5 cases). '-Could not tell whether the observed pinger effect was caused by the sound produced by the pingers or by the presence of something novel hanging from the net. '- possible direct or inadvertent manipulation of the results by the observers or the fishermen. '-might not be long enough of a study to determine habituation.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	Pingers significantly reduced total cetacean and pinniped entanglement in drift gill nets without significantly affecting swordfish or shark catch. *"We believe that pingers are unlikely to reduce the bycatch of all cetacean species or all pinniped species".*
Application to NZ inshore fisheries	Relevant for designing a NZ experiment. Similar taxa bycatch
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment. Shows that it is inherently difficult to control differences in sampling protocol and data collection using real fisheries examples. Similar taxa bycatch (i.e. bottlenose dolphins and sealions)
Costs	Large amounts of pingers used in real fishery example. Very expensive. Requires MM deaths to be able to determine success.
Benefits	Able to be performed on existing fisheries. Accounts for a lot of variables in sampling protocol associated with fishing.

Number	4
Reference	Berrow et al 2008
Year	2008
Study name	Effect of acoustic deterrents on the behaviour of common dolphins (Delphinus delphis)
Fishing gear	Discusses gillnets and pelagic trawling, but no nets used.
MM bycatch (test) species	Short beaked common dolphin (Delphinus delphis)
Key finding	Significant modification of the signal type or source level may be more effective, but our results suggest that pingers, at their current state of development, may not provide a consistently effective deterrent signal for common dolphins. Although both devices were only tested on one dolphin group in the present study, the contrasting results suggest that intra-specific differences occur in the reaction of common dolphins to acoustic stimuli, which may be due to differences in spatial, temporal or other variables
Assumed causal agent for avoidance?	- acoustic devices permit animals to associate an escape route with the acoustic signal at the mouth of the trawl
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: small sample size, low level of sampling/testing effort, no statistical tests. Many uncontrolled variables.
Caveats or uncertainties to methods	-No statistical tests used. '-the RP did not always log its own activation, not a reliable estimate of dolphin clicks… or activation '-vessel was moving when acoustic alarms were being used - this means the depth of water could have varied and the acoustic properties of the area. Could have created acoustic interference. '-No estimates of ambient noise. '-trial 1 and 2 used a different method (pingers and hydrophone on moving vessel), Trial 3 attached the pinger to a RIB, which was stationary (while the other vessel with the dolphins moved towards the RIB). '-Dolphins are attracted to the vessel for bow wave riding. Not foraging behaviour... '-controls were not deployed consistently (none in second trial) - controls only collected for short time periods (<2min per recording). '-Although the same group of dolphins were sometimes subjected to a number of consecutive tests, up to 14 different dolphin groups, ranging in size and in composition, including adults, juveniles and calves were exposed to pingers or acoustic deterrent signals over the course of the study. '-controlled exposure experiments presented here are in stark contrast to the noisy, complex environment around an active fishing trawl,
Exhibited avoidance?	N
Reduced bycatch?	N
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Pingers did not provide a consistently effective deterrent signal for common dolphin
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Methods useful for developing testing NZ assemblages.
Costs	Low
Benefits	Local, investigates taxa of concern.

Number	5
Reference	2002
Year	Reducing incidental mortality of Francisana dolphin Potoporia blainvillei with acoustic warning devices attached to fishing nets.
Study name	Gillnet
Fishing gear	Franciscana dolphin (Pontoporia blainvillei)
MM bycatch (test) species	"A highly significant reduction in bycatch for this species. However, sea-lions (*Otaria flavescens*) damaged the fish in active pinger nets significantly more than silent nets, and the damage increased over the course of the experiment.
Key finding	
Assumed causal agent for avoidance?	61% of entangles dolphins were females and 56% of the females were immature. Necropsies also revealed that 5 of 17 retrieved females were pregnant. Among males 90% were immature.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	
Caveats or uncertainties to methods	Entangled dolphins were not eating the target species of the fishery."
Exhibited avoidance?	"Two mechanisms could account for a dolphin's
Reduced bycatch?	entanglement in this case: (1) dolphins do not detect the net or do not perceive it as dangerous, or (2) dolphins are not using echolocation while traveling between feeding areas
Maintained target catch	
Level of efficacy (reducing bycatch, maintaining target catch)	Other issues discussed:
Application to NZ inshore fisheries	'-dinner bell effect
Relevance to protected dolphin species assemblages in NZ	'-habituation"
Costs	Moderate: medium sized dataset. Data on fishing gear, environmental variables and bycatch rates were recorded by fishery observers . Some trends that perhaps should have been discussed.
Benefits	"-considers historic fisheries capture rates.

Number	6
Reference	Brotons *et al*. 2008b
Year	2008
Study name	Do pingers reduce interactions between bottlenose dolphins and nets around the Balearic Islands?
Fishing gear	Demersal gill net
MM bycatch (test) species	Bottlenose dolphin (Tursiops truncatus)
Key finding	Net interaction rates were significantly reduced by 49% with active pingers, but not all brands were equally effective. Catch yields were increased by 9% with active pingers, though not significantly. The largest increase in PPUE was seen in the conditions where pingers were inactive. As previous work on this fishery has shown that there is a strong seasonal effect on both dolphin-net interaction rates and profit per unit effort, PPUE (Brotons et al. 2007), While all brands showed some reduction in the active condition compared to the no-pinger control, only the reduction for Aquatec pingers was significant (p = 0.0064, Table 3). These pingers reduced the net interaction rate by 70% in active nets. We have shown that pingers may have potential as an effective mitigation measure, but our results are not conclusive and additional research must be conducted. If pingers are introduced, long-term study will be absolutely essential to monitor the impact of pingers on mortality levels and to monitor the possibility of habituation and/or sensitisation to the pinger stimuli. Furthermore, the widespread introduction of pingers into this fishery would significantly change the acoustic ecology of Balearic coastal waters and monitoring the effects of this change on the dolphin population would be important.
Assumed causal agent for avoidance?	Reasons for avoidance were not discussed. Pingers represented a novel stimulus to the dolphins and we are unable to predict whether and how rapidly they may habituate to these sounds, especially under varying motivational conditions, such as increased hunger if fish stocks become further reduced. If animals learn to associate the pinger sounds with the presence of fish, then the interaction may even be worsened by pinger use. The cognitive abilities of bottlenose dolphins suggest that habituation may occur readily.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Moderate: Some uncertainties and assumptions, comparable to other pinger studies, power analysis, many variables controlled (Identical nets for 59 ships) and multiple contributing factors included in PPUE measure.
Caveats or uncertainties to methods	-Although vessels were assigned to treatments at random within cooperatives, treatments were distributed as equally as possible across localities to minimise the effect of geographic area, as we have previously found net interactions rates to vary considerably across areas (Brotons et al.2007). '-There was no attempt to verify the accuracy of the acoustic properties of the pingers '-Since interaction with the net through depredation is a prerequisite for entanglement in it, we used the frequency of net interaction as a measure of bycatch risk, so that our results were not dependent on actual mortality for interpretation. '- power calculations assumed a balanced design, which there was not. '-sample sizes must be adequate with respect to the natural variability of the response measure, so we note that the variability inherent in both our response measures is such that future studies of pinger effectiveness will require substantial sampling effort, at least equivalent to that we report here. Of course, the observed effect size should be considered against observed bycatch rates and reduction targets if they exist. Ideally, results from bycatch mitigation experiments would be compared to baseline bycatch data. '-All types of dolphin interactions with nets were used as a proxy for risk of fatal entanglement.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Shows potential for reducing net interactions, but requires further research
Application to NZ inshore fisheries	Performed in depths up to 60m
Relevance to protected dolphin species assemblages in NZ	Bottlenose dolphin is in NZ also.
Costs	Net interactions represented an economic cost, from fish loss and net damage, of 6.5% (95% CI: 1.6 to 12.3% of the total landed catch value (Brotons et al. 2007). Bycatch mortality may reach between 30 and 60 dolphins annually, although there are no reliable current estimates (for more information see Brotons et al. 2007). Requires MM deaths to be able to determine success.
Benefits	Defined by PPUE. Catch yields were increased by 9% with active pingers, though not significantly. The largest increase in PPUE was seen in the conditions where pingers were inactive.

Number	7
Reference	Buscaino et al. 2009
Year	2009
Study name	Pinger affects fish catch efficiency and damage to bottom gill nets related to bottlenose dolphins
Fishing gear	Demersal gill net
MM bycatch (test) species	Bottlenose dolphin (Tursiops truncatus)
Key finding	The net equipped with pingers contained 28% more fish biomass and was less damaged (though this was not the case on a haul by haul basis but averaged over the course of the year).
Assumed causal agent for avoidance?	- fish exposed to excessive sound conditions may suffer reduced fitness [31, 32]. This reduced fitness could potentially impact by hampering their ability to sense their entire acoustic environment. Thought the results of this study suggest otherwise (Larger catch with pingers). '-, it is not still clear how the pinger exerts this effect [19, 38, 39]. Indeed, the pinger may have a startling, annoying or alerting [14, 38] effect on dolphins.... they did not show any escape behaviour (G. Buffa et al., unpublished data), leading us to consider that the effect of the pinger is that of annoyance as they are detecting entangled fish in the pinger net. Raised two questions: (1) if dolphins are able to adapt their behaviour to the acoustic devices, and (2) what is the magnitude of acoustical pollution generated by a wide use of pingers.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: small sample size, unbalanced design, low statistical power, not a true fishery, interannual /seasonal variables not controlled, high level of uncertainty/caveats.
Caveats or uncertainties to methods	-Low sample size and statistical power. '-Non-fishery experiments to assess pinger effectiveness. '-Twenty-nine hauls in total, each consisting of a pinger net and control net. '-Cause of net damage assessed subjectively. '-Fishermen determined whether holes were caused by dolphins, rather than fish, vessel or seafloor contact, or other operational factors. '- the nets became more hole-filled (and ribbon covered throughout the study. '-Only one pinger tested.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	The net equipped with pingers contained 28% more fish biomass and was less damaged (suggesting less dolphin bycatch).
Application to NZ inshore fisheries	Performed in depths from 15 to 40m
Relevance to protected dolphin species assemblages in NZ	Bottlenose dolphin is in NZ also.
Costs	Four pingers per net.
Benefits	The results from this study show that pingers fitted to bottom gill nets have a significant effect on the fish biomass of the catch (?28%) and damage inflicted by dolphins on the nets (-31%), therefore reducing the economic loss suffered by fishermen.

Number	8
Reference	Carretta & Barlow 2011
Year	2011
Study name	Long-Term Effectiveness, Failure Rates, and “Dinner Bell” Properties of Acoustic Pingers in a Gillnet Fishery
Fishing gear	Drift gill net
MM bycatch (test) species	Common dolphin (Delphinus delphis), California sea lion (*Zalophus californianus*) Northern elephant seal (*Mirounga angustirostris*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), Northern right whale dolphin (*Lissodelphis borealis*) + all cetaceans and all pinnipeds
Key finding	The proportion of sets with cetacean bycatch was significantly lower (p = 6.7 × 10−7) in sets with ≥30 pingers (4.4% of sets with bycatch) than in sets without pingers (8.4% of sets). Common dolphin bycatch rates on sets with ≥30 pingers were nearly 50% lower than those without pingers. Bycatch of other cetaceans was not significantly affected by pinger use; however, sample sizes were small. Beaked whales were not observed bycaught since 1 year prior to pinger use. Bycatch was 10x greater when >1 pinger failed. Over 14 years there was no evidence of habituation.
Assumed causal agent for avoidance?	-habituation '-Dinner bell effect '-Failure rates
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Moderate to high: Large dataset. Data on fishing gear, environmental variables and bycatch rates were recorded over 8,000 sets by fishery observers over a period of 19 years. Some uncertainties.
Caveats or uncertainties to methods	-It is not practical to observe every vessel in the fishery, because some smaller vessels lack berthing space for observers. '-analyses of sets with pingers include only those that were a minimum of 1,500 m in length with ≥30 pingers. '-excluded species with fewer than 10 total bycatch events from the analysis. '-Pingers were not used in this fishery prior to the 1996–1997 experiment and pingers have been used in >99% of all observed sets since 1998. For these reasons, we are unable to assess the potential year effect on bycatch rates and pinger effectiveness (can only compare pre-post data, not interannual changes). '-Beginning in 2001, fishery observers were instructed to listen to each pinger during the first set retrieval of a fishing trip. ...small sample set. '-Large dataset. Data on fishing gear, environmental variables and bycatch rates were recorded over 8,000 sets by fishery observers over a period of 19 years. During the last 14 years, over 4,000 sets were fitted with pingers. Sample size for examining the effect of pinger failure was small. Attempts were made to standardise sets used in analyses for variables such as mesh size, net length and soak time. '-More than one pinger failed in 3.7% of observed sets. In those where pinger failure rate was recorded, this was found to occur for ~18% of deployed pingers. Observers sometimes failed to detect non-functioning pingers, so this failure rate is likely greater than recorded. '-An increasing fraction of fishing Is conducted by vessels too small to accommodate observers. Pinger compliance and effectiveness could not be evaluated for this portion of the fishery, potentially biasing results. '-Depth considered as a variable factor. Distance from shore not considered. '-'-background population decline needs to be considered.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	The proportion of sets with cetacean bycatch was significantly lower in sets with ≥30 pingers (4.4% of sets with bycatch) than in sets without pingers (8.4% of sets).
Application to NZ inshore fisheries	100-1,902m. Distance from shore not considered.
Relevance to protected dolphin species assemblages in NZ	Common dolphin is in NZ also. Considers influence from pinnipeds and other relevant MM community members also.
Costs	Low cost investigation, using existing data, and augmenting existing observer program. Requires MM deaths to be able to determine success.
Benefits	Shows dramatic improvement, though population decline needs to be considered.

Number	9
Reference	Carretta et al. 2008
Year	2008
Study name	Acoustic pingers eliminate beaked whale bycatch in a gill net fishery
Fishing gear	Drift gill net
MM bycatch (test) species	Beaked whales
Key finding	Beaked whale bycatch dropped from 33 beaked whales in 3303 sets during the first 6 years of the observer program, to none in 4381 sets over the last 10 years while pingers were in use. Results suggest beaked whales may be among the most sensitive cetacean taxa to pinger frequencies. The difference in beaked whale entanglement rates with and without pingers is so large that it cannot be explained as a sampling artifact (though population decline of toothed whales needs to be considered). In contrast, bycatch rates of all cetaceans (mostly dolphins) decreased by only 50% over the same period.
Assumed causal agent for avoidance?	-Three significant regulatory changes have occurred in this fishery since 1996: the introduction of acoustic pingers, a mandatory increase in minimum fishing depth to 11 m, and a seasonal area closure implemented in 2001 that shifted fishing effort to the south (Fig. 3). Of these changes, the introduction of pingers is the most likely factor in the reduction of beaked whale bycatch.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Moderate: Some uncertainties and assumptions, large dataset, low level of statistical analysis used.
Caveats or uncertainties to methods	-the nets are at 11–22 m depth and the bottoms are at 75–90 m depth. Regulations require that acoustic pingers be attached every 91 m and within 9 m of the floatline, and every 91 m and within 11 m of the leadline. Thus, the average net contains approximately 40 pingers. '-Survey-specific estimates of beaked whale abundance declined by 62% over this period, but some of that apparent decline is attributed to rougher weather during later surveys. '-background population decline needs to be considered.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Beaked whale bycatch dropped 100%, bycatch rates of all cetaceans (mostly dolphins) decreased by only 50% over the same period
Application to NZ inshore fisheries	Distance from shore/depth did not appear to have been considered, but the bottom net depth is between 11m to >90m (100-1,902m provided in subsequent paper)
Relevance to protected dolphin species assemblages in NZ	Captures pre-pinger: 21 Cuvier's beaked whales (*Ziphius cavirostris*), 5 Hubb's beaked whales (*Mesoplodon carlhubbsi*), 1 Stejneger's beaked whale (*M. stejnegeri*), 1 Baird's beaked whale (*Berardius bairdii*), 2 unidentified *Mesoplodon* species, and three "unidentified ziphiids"
Costs	Low cost investigation, using existing data Requires MM deaths to be able to determine success.
Benefits	Shows dramatic improvement, though population decline needs to be considered.

Number	10
Reference	Cox et al 2001
Year	2001
Study name	Will harbour porpoises (Phocoena phocoena) habituate to pingers?
Fishing gear	Gillnet discussed; static mooring used
MM bycatch (test) species	Harbour porpoises (Phocoena phocoena)
Key finding	These results indicate that porpoises habituated to the Dukane NetMark™ 1000 pinger and are not alerted to echolocate in the presence of nets by pingers. The proportion of intervals in which echolocation events occurred was significantly reduced when the pinger was activated, suggesting that porpoises echolocate less frequently in the vicinity of an active pinger.
Assumed causal agent for avoidance?	This study was not designed to test hypotheses of the mechanism by which pingers reduce harbour porpoise bycatch but was able to reject the hypothesis that pingers stimulate harbour porpoises to echolocate and thus detect a gillnet.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low - moderate: Controlled experiment testing. Small sample size, though good statistical methods used. Not a fishing trial, difficult to compare. Multiple exposure for same porpoises. Only tested one pinger.
Caveats or uncertainties to methods	-Poor weather forced truncation of the second trial. Thus, the sample size was small, so both experiments were pooled to increase the power and test the mean-fit model. Results of the mean-shift model for both experimental trials and the pooled trials are presented in Table 2. '-individual porpoises likely experienced multiple exposures to the pinger over the course of the experiment '-The experimental protocol involved only a single pinger on a mooring, so it is not possible to say with certainty that porpoises will habituate to pingers attached to a gillnet.
Exhibited avoidance?	Y, but exhibited habituation
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	The analysis suggests that porpoises habituated to the presence of the pinger.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	Low
Benefits	Local, investigates taxa of concern. No bycatch required.

Number	11
Reference	Cox et al 2003
Year	2003
Study name	Behavioral responses of bottlenose dolphins, Tursiops truncatus, to gillnets and acoustic alarms
Fishing gear	Gillnet
MM bycatch (test) species	Bottlenose dolphin (*Tursiops truncatus*)
Key finding	We conclude that pingers are unlikely to reduce bycatch of bottlenose dolphins in gillnet fisheries along the US east coast because of the limited behavioural responses we observed in our experiment. Dolphins entered the zone of vulnerability significantly more frequently when the pingers were off than when they were on. Fish catch did not vary with treatment. bottlenose dolphins diverted their travel around the net only slightly when the pingers were active, often traveling just inshore or offshore of the buoys demarcating the ends of the net. This result is markedly different from that exhibited by harbour porpoises. dolphins may learn to associate the pinger with the presence of a gillnet that contains fish. This is supported by the behaviour of the dolphins around the fishing boat and net in this experiment. On several occasions when we started hauling the net, dolphins moved very rapidly towards the boat from over 300 m away. We can identify four types of interactions: (1) dolphins taking fish from the net, (2) dolphins begging fish from fishing vessels, (3) dolphins using the net as a barrier to herd fish as a foraging tactic, and (4) dolphins transiting around the net without interacting with it.
Assumed causal agent for avoidance?	dinner bell effect habituation
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low - moderate: Controlled experiment testing. Small sample size, though reasonable statistical methods used. Imitates a fishing trial, difficult to compare to true fisheries. Only tested three pingers and one net.
Caveats or uncertainties to methods	-terminated tracking and field effort if the Beaufort Sea State exceeded 3 '-short seasonal investigation. '-only a single net tested and three pingers. '-uses zone of vulnerability as a proxy for bycatch.
Exhibited avoidance?	N
Reduced bycatch?	N
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	Pingers are unlikely to reduce bycatch of bottlenose dolphins in gillnet fisheries along the US east coast. Fish catch did not vary with treatment.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	Moderate costs could result in MM deaths to be able to determine success.
Benefits	Mimics real fisheries without as much bycatch risk. (no dolphins caught in trials)

Number	12
Reference	Cruz et al 2014
Year	2014
Study name	Risso's dolphin depredation in the Azorean hand-jig squid fishery: assessing the impacts and evaluating effectiveness of acoustic deterrents
Fishing gear	Hand-jig
MM bycatch (test) species	Risso's dolphins (*Grampus griseus*)
Key finding	The use of pingers had no significant effect on the catch per unit effort of squids. Depredation rates were similar for the control (0.20), inactive (0.19), and active (0.19) pinger conditions. Models indicated no significant effect of pinger brand and condition on cetacean depredation.
Assumed causal agent for avoidance?	NA
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: small sample size, low level of sampling/testing effort, low levels of significance in statistical tests. Many uncontrolled variables.
Caveats or uncertainties to methods	Compares previous studies from multiple gillnet pingers to this study that only had a single pinger located on the vessel itself. Not comparable methodologies. Effective pinger distance was not considered. On several occasions, it was not possible to carry out the five trials during a fishing trip due to degradation of sea state or shifts in fishing area. The pinger was attached to a rope and deployed from the bow of the fishing boat Risso's dolphins were responsible for all depredation events. Risso's dolphins depredated on average 3 squids per trip - very low depredation rate?? Depredation was not responsible for significant decreases in squid catches or for a significant decrease in CPUE. frequency and magnitude of depredation varied considerably between months, but levels of observer coverage were low and insufficient to accurately capture this variability. This maybe the reason pingers don't appear to be working to reduce depredation. What is the background noise in a squid fishery, would the dolphins be able to hear the pinger? Fishing activity was generally concentrated close to coast, with fishers starting their activity at dawn at shallower depths and moving to deeper waters as the day progresses. This could influence the pinger sound? Models explained a low percentage of variability in the data. We suspect this was mainly caused by lack of information on some important factors driving Risso's dolphin interaction on the squid fishery, including squid abundance and patchiness and Risso's dolphin abundance. most of the fishery observer data were collected during spring and summer when depredation was lower, thus underestimating depredation rates. estimates of depredation rates assume that dolphins did not select larger or smaller squids and that squids captured during a fishing event were representative of depredated squids
Exhibited avoidance?	N
Reduced bycatch?	N
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	The dolphins were not deterred by the sound produced by the pingers used. The use of pingers had no significant effect on the catch per unit effort of squids.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	Low pinger costs could result in MM deaths to be able to determine success.
Benefits	Able to be performed on existing fisheries.

Number	13
Reference	Dawson and Lusseau 2012
Year	2012
Study name	Pseudo-replication confounds the assessment of long-distance detection of gillnets by porpoises: Comment on Nielsen et al.(2012)
Fishing gear	Gillnet discussed, but no nets used.
MM bycatch (test) species	Harbour porpoises (Phocoena phocoena)
Key finding	They claimed to provide evidence that porpoises detected gillnets at distances >80 m, much farther than was thought possible. We show, however, that their results are undermined by pseudo-replication, and hence that their conclusion is unreliable. Mixed-effects modelling can be used to avoid this problem
Assumed causal agent for avoidance?	NA
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	NA
Caveats or uncertainties to methods	NA
Exhibited avoidance?	NA
Reduced bycatch?	NA
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	NA
Application to NZ inshore fisheries	NA
Relevance to protected dolphin species assemblages in NZ	NA
Costs	NA
Benefits	NA

Number	14
Reference	Dawson and Slooten 2005
Year	2005
Study name	Management of gillnet bycatch of cetaceans in New Zealand
Fishing gear	Gill net
MM bycatch (test) species	Hector's / Maui dolphin (*Cephalorhynchus hectori*), Bottlenose dolphin (*Tursiops truncatus*)
Key finding	It is impossible to say whether pingers are effective in reducing entanglements of Hector's dolphin, for two reasons. Firstly, because pingers are used in combination with several other measures intended to reduce entanglement rate, their effect (if any) is hidden. Secondly, there has been insufficient observer coverage to determine whether these measures, even in combination, are effective. More observer coverage is needed to determine whether pingers significantly reduce incidental capture. If a target of 80% reduction in bycatch is set and a nominal value of a=0.10 is accepted, it would take approximately 320 observed sets to detect a significant difference with 80% power.
Assumed causal agent for avoidance?	NA
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: simplistic statistics
Caveats or uncertainties to methods	-small sample size for power analysis, no area or season effects considered.
Exhibited avoidance?	IND
Reduced bycatch?	IND
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	More observer coverage is needed to determine whether pingers significantly reduce incidental capture. Given that fishermen have implemented several changes simultaneously.
Application to NZ inshore fisheries	Specific to NZ
Relevance to protected dolphin species assemblages in NZ	Maui, Hectors, and bottlenose discussed.
Costs	Low
Benefits	Local, investigates taxa of concern.

Number	15
Reference	Dawson et al. 1998
Year	1998
Study name	Pingers, Porpoises and Power: Uncertainties with using pingers to reduce bycatch of small cetaceans
Fishing gear	Gillnet discussed; no nets used.
MM bycatch (test) species	Dolphins (*Delphinidae*) and porpoises (*Phocoenidae*)
Key finding	Statistical power analyses indicate that field based bycatch studies are feasible only in areas of high entanglement rate. Kraus et al.1997 study was exemplary in its design and execution. Importantly, the experiment took place in an area of high bycatch rates. Neither fishers nor independent observers knew which pingers were active. The experiment was designed following a statistical power analysis of the scale needed to detect a 50% difference, and the design was balanced (equal numbers of control and experimental sets). These basic aspects of good experimental design have been lacking in most previous studies (Dawson, 1994). While pinger study costs could certainly be reduced, scientists and managers must realise that robust tests of pinger effectiveness will be expensive. Such studies may need to be continued over many seasons to produce a reliable result.
Assumed causal agent for avoidance?	Recommends that experiments should test whether the success of the 1994 experiment was mediated via the behaviour of the prey of harbour porpoises. Anecdotal reports suggest that pingers reduce the catch of target species in fisheries for alosids and clupeids (IWC, in press). Detailed experimental observations are required to confirm or refute these reports and provide information on the mechanism(s) by which porpoise bycatch was reduced in the 1994 experiment.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Has recommendations to improve scientific rigor: 1. Replication of results in time and space. 2. Research on habituation. 3. Research on causation. 4. General issues (e.g. sound overloading in the ocean, effects to target catch, wider effects)
Caveats or uncertainties to methods	-Practical constraints include the size, cost, and battery life of current pingers. and whether their use could be monitored cost-effectively. '-influence of pingers on other pinniped taxa should also be considered alongside cetacean bycatch reduction success, as they could become attracted.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Although we are cautiously enthusiastic about their promise, there is currently no justification for adopting pingers as a panacea for the problem of incidental mortality of small cetaceans in gillnets.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Methods useful for testing NZ assemblages.
Costs	Low costs for a literature review
Benefits	Summarises all available literature to 1998

Number	16
Reference	Dawson et al. 2013
Year	2013
Study name	To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnet fisheries
Fishing gear	Gill net, drift net
MM bycatch (test) species	Various small cetaceans
Key finding	Overall, pingers show promise for neophobic species with large home ranges. Significant reductions in bycatch of harbour porpoise, Franciscana, common dolphin, striped dolphin and beaked whales have been demonstrated. Two long-term studies show no sign of habituation. Studies on depredation mitigation show small, inconsistent improvements in fish catch and some reduction in net damage. There is no evidence that pingers which are specifically designed to reduce depredation (and hence are louder) are any more effective in reducing entanglement than the quieter devices designed to reduce entanglement of porpoises. It seems that bottlenose dolphins are likely to tolerate even high-output pingers if there is a food 'reward'. Have been particularly successful for harbour porpoise, with large reductions in bycatch over much of the species' range using a variety of pinger types. Unreasonable however, to expect similar success for all species. Several risks remain, such as habitat exclusion for species with restricted ranges. Delphinids, particularly those showing very flexible behaviour, coastal distribution and high site fidelity, such as bottlenose dolphins, would seem among the least appropriate candidate species. Small-scale fisheries in the developing world are also unlikely to have economic resources to implement this mitigation method. Necessary to have a target for bycatch reduction as without a quantitative goal it is not possible to assess efficiency. Power analyses should be used to determine sample size needed to detect meaningful effects. Non-compliance of pinger functioning and spacing can lead to an increase in MM bycatch. Most pinger types showed significant operational problems, including time taken in attachment, difficulty of checking functionality, propensity for tangling the gear and unreliability. For some pinger types failure rates exceeded 50%. We recommend that a well-designed observational study of the behavioural reactions to pingers be conducted, in as realistic a situation as feasible (e.g. Cox et al. 2001), before employing pingers in full-scale field trials with any novel species.
Assumed causal agent for avoidance?	Most likely a combination of: Avoidance/aversive sound. Management tools (high levels of compliance) bycatch species type (more easily startled species) Considered: Reductions in depredation (Dinner bell effect) Habitation Less effective in real fisheries (where compliance is low). Stimulating echolocation increasing net detection Indirect prey effects. Pinger spacing
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	NA
Caveats or uncertainties to methods	-Some literature reviewed was unpublished, though data were critically assessed before inclusion in this review. '-The theodolite is used to estimate the position of individual animals or groups of animals at the surface. This allows researchers to compare closest approach distances when pingers are active and silent and, thus, to determine whether animals are displaced by the sound of the device. Unfortunately, several studies have considered each surfacing as an independent event, when in fact they are auto-correlated. This inflates sample size and can result in a falsely significant statistical test. The simplest way around this problem is to use only the closest observed approach distance for each group of dolphins or porpoises (Dawson & Lusseau 2005). '-In at least 2 cases, however, trials with pingers have not shown any reduction in bottlenose dolphin depredation of gillnets in the Mediterranean. Neither study has been formally published, which underscores the problem that negative results are less likely to be published. In some cases it may be impractical, or even unethical, to attempt to demonstrate the

	effectiveness of pingers in reducing bycatch. This may be because bycatch rates are very low, resulting in a requirement for extremely large (and costly) sample sizes (Dawson et al. 1998), or because the mortality of even a few individuals in a controlled experimental trial is unwarranted or unacceptable (e.g. Maui Dolphin). Quality control in pinger manufacture needs to improve. In addition to the reliability issues addressed earlier, there can be substantial variation in sound pressure level among pingers of the same brand and model. Displacement from key habitat could be an issue at smaller scales/restricted ranges. We note that the sound field generated by pingers will vary across locations (Shapiro et al. 2009), and behavioural responses will not be uniform Spacing of pingers has generally been shown to be effective at <92m spacing. More investigation required. Continued lack of compliance has led scientists on the Take Reduction Team to conclude that it is time to look for alternative mitigation strategies in New England.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	generally effective in reducing larger and more easily startled cetacean bycatch
Application to NZ inshore fisheries	Distance from shore/depth did not appear to have been compared between studies, other than saying they are controlled in most experiments.
Relevance to protected dolphin species assemblages in NZ	Maui, Hectors, and bottlenose discussed.
Costs	Low cost investigation, reviewing existing studies.
Benefits	low cost, develops good questions for future investigation.

Number	17
Reference	Erbe & McPherson 2012
Year	2012
Study name	Acoustic characterisation of bycatch mitigation pingers on shark control nets in Queensland, Australia
Fishing gear	Shark control nets
MM bycatch (test) species	Humpback whale (*Megaptera novaeangliae*), Indo-Pacific bottlenose dolphin (*Tursiops aduncus*), Bottlenose dolphin (*Tursiops truncatus*), Indo-Pacific humpback dolphin (*Sousa cinensis*), Common dolphin (*Delphinus delphis*), Australian snubfin dolphin (*Orcaella heinsohni*), Dugong (*Dugong dugon*)
Key finding	This study (1) measured the acoustic output of Fumunda F3 and F10 pingers used on shark nets by the QSCP, (2) modelled sound propagation, (3) measured ambient noise off the Queensland coast and (4) reviewed the literature to derive the hearing sensitivities of local marine mammals. Pingers tested were found to be detectable by all species and were installed at appropriate spacing to highlight the net to all animals travelling parallel or perpendicular to the net. While Fumunda pingers are amongst the quietest pingers commercially available, we showed that they are a feasible choice in this environment and for these specific species. The advantage of using such quiet pingers is their minimal contribution to the overall noise budget. Beyond 1.5 km, pingers no longer contributed significantly to the ambient noise budget. Ultimately, impact is determined by more than a noise budget and must include an animal's sensitivity to the sound.
Assumed causal agent for avoidance?	Audible sound (though the study does not try to predict animal behaviour, just that specific animals can hear the pingers.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: between pinger variability, small sample size, low level of sampling/testing effort. Many uncertainties/limitations.
Caveats or uncertainties to methods	-Not directly applicable to fisheries applications (this was a shark net study). '-small sample size of pingers. Deployed seasonally for one type. '-Pinger output varied with individual pingers and with direction; the mean levels were used in the model of detectability. '- Sound propagation was modelled based on typical Gold Coast conditions, but will vary with e.g. temperature, time of day, and season. '-Hearing sensitivity has not been measured for humpback whales, dugongs and some of the local dolphin species, and had to be estimated based on reported behavioural responses, anatomical studies and measurements on related species. '-Our study focussed on pinger detectability in the specific ambient noise and sound propagation environment of the Gold Coast. In other environments, and for other target species, the pingers likely require a different arrangement and perhaps different frequencies and SLs. '-This study is a feasibility study, showing that specific pingers in a specific arrangement within a specific environment are audible to specific species. They did not attempt to predict animal behaviour. For a sound to induce a behavioural change, the received level might have to be somewhat larger than the detection level. '-It would also be useful to measure at what time into a deployment the battery power becomes inadequate to sustain sufficient output levels, in order to advise on recovery times. '-For potential future studies on behavioural responses of marine mammals to pingers, the received sound level should be measured in the field at the time, rather than relying on the manufacturers' specifications in combination with a simple (e.g. geometrical) sound propagation model.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	While Fumunda pingers are amongst the quietest pingers commercially available, we showed that they are a feasible choice in this environment and for these specific species.
Application to NZ inshore fisheries	Some bycatch taxa relevant to NZ - not fisheries related. Different type of net used.
Relevance to protected dolphin species assemblages in NZ	Same species as found in NZ
Costs	Low (cost of pingers, data extraction and interpretation, modelling and pinger deployment to existing nets)
Benefits	The advantage of using such quiet pingers is their minimal contribution to the overall noise budget.

Number	18
Reference	FAO 2018
Year	2018
Study name	Report of the Expert Workshop on Means and Methods for Reducing Marine Mammal Mortality in Fishing and Aquaculture Operations.
Fishing gear	Various discussed, no nets used.
MM bycatch (test) species	Various
Key finding	The workshop agreed that acoustic deterrents such as pingers can be effective but should not be considered as the 'go-to' mitigation measure or a 'quick fix' to the problem because their effectiveness may be spatially, temporally and fishery dependent, and species-specific. Further, acoustic deterrents may reduce bycatch but they usually do not eliminate bycatch. Summaries of studies using pingers are available through a search of the bycatch.org database by using the search term "acoustic deterrents." Gives a good outline of when evaluation for pinger use should be carried out...e.g. is it critical habitat? will it cause the MM to aggregate in a habitat that puts them at greater threat, Lethal sub-lethal effects? Low population size, will the ADD increase other MM interactions, habituation, consequences to other species?
Assumed causal agent for avoidance?	Not discussed
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Discusses the successes and failures of pinger investigations.
Caveats or uncertainties to methods	NA
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	IND
Level of efficacy (reducing bycatch, maintaining target catch)	Pingers can be effective but should not be considered as the 'go-to' mitigation measure or a 'quick fix' to the problem because their effectiveness may be spatially, temporally and fishery dependent, and species-specific.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment / provides information on considerations.
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	Low cost
Benefits	Summarises findings from key investigations but refers to https://www.bycatch.org/ for all available literature to 2018.

Number	19
Reference	Gazo et al. 2008
Year	2008
Study name	Pingers as deterrents of bottlenose dolphins interacting with trammel nets
Fishing gear	Trammel net
MM bycatch (test) species	Bottlenose dolphin (Tursiops truncatus)
Key finding	No significant differences were observed between the catch of red mullet by the three monitored boats. This result was independent of the setting condition used. The use of pingers had no significant incidence on the catch of red mullet. Nets equipped with pingers received less damage (87% fewer holes) than nets with non-functional devices or without pingers. Predation in nets equipped with operative pingers appeared to be reduced by about 50% from those equipped with either non-operative pingers or no pingers.
Assumed causal agent for avoidance?	Discusses: '-annoyance '-habituation '-Dinner bell effect '-Failure rates '-prey species avoidance Also discussed: '-habitat loss through overuse. '-overall increases in noise pollution in an already noisy location.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: small sample size, low level of sampling/testing effort, simplistic statistics.
Caveats or uncertainties to methods	- small sample size, low level of sampling/testing effort, simplistic statistics. '- Observers counted and identified holes in this study, but it was noted that damages to the gear are more likely to be caused by operational factors, particularly interaction with the rocky seafloor. Fishermen were not consistent either in the identification of the holes that they attributed to dolphin interaction or in the cause of the damage to some of the fish caught. Thus, assessment of dolphin interaction that only considers the presence of holes or of spoiled fish is likely to be misleading. '-not clear how other environmental variable were controlled.
Exhibited avoidance?	N
Reduced bycatch?	Y
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	Pingers did not prevent dolphins approaching nets, but those nets equipped with active pingers received 87% less damage. Predation in nets reduced by ~50% with pinger use. No significant effect on target species catch.
Application to NZ inshore fisheries	Fisheries operated in an area of about 340 km2. Testing locations were at approx. 50m depth.
Relevance to protected dolphin species assemblages in NZ	Same species as found in NZ
Costs	Moderate costs Requires MM deaths to be able to determine success.
Benefits	Able to be performed on existing fisheries.

Number	20
Reference	Gonener & Bilgin 2009
Year	2009
Study name	The Effect of Pingers on Harbour Porpoise, *Phocoena* Bycatch and Fishing Effort in the Turbot Gill Net Fishery in the Turkish Black Sea Coast
Fishing gear	Gillnet
MM bycatch (test) species	Harbour porpoise (Phocoena phocoena)
Key finding	Pingers significantly reduced bycatch. Target fish catch rate increased with pinger use though fish size was not affected.
Assumed causal agent for avoidance?	-habituation recommended for further investigation
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: small sample size, low level of sampling/testing effort, simplistic statistics. Not all variables managed.
Caveats or uncertainties to methods	- variable water depth for testing - sea trials were conducted from 17.2 to 183.2 m water depth. '- variable soak times (168-288 hours) ;-damage to nets was not considered. '-not clear if the fishermen collected the data, or observers. '-Two test trips were performed on the same date.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	Pingers significantly reduced bycatch. Target fish catch rate increased with pinger use though fish size was not affected.
Application to NZ inshore fisheries	Sea trials were conducted from 17.2 to 183.2 m water depth
Relevance to protected dolphin species assemblages in NZ	Similar inshore fishing depths
Costs	Moderate costs Requires MM deaths to be able to determine success.
Benefits	Able to be performed on existing fisheries.

Number	21
Reference	Hamer et al 2012
Year	2012
Study name	Odontocete bycatch and depredation in longline fisheries: A review of available literature and of potential solutions
Fishing gear	Longline discussed, but no nets used
MM bycatch (test) species	Various odontocete
Key finding	Recent developments in acoustic and physical mitigation technologies have yielded mixed results. Acoustic mitigation technologies have no moving parts, although require complex electronics. To date, they are insufficiently developed, and their efficacy has been difficult to assess.
Assumed causal agent for avoidance?	NA
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	NA
Caveats or uncertainties to methods	NA
Exhibited avoidance?	IND
Reduced bycatch?	IND
Maintained target catch	IND
Level of efficacy (reducing bycatch, maintaining target catch)	To date, they are insufficiently developed, and their efficacy has been difficult to assess.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	Low
Benefits	Summarises all available literature to 2012

Number	22
Reference	Hamilton and Baker 2019
Year	2019
Study name	Technical mitigation to reduce marine mammal bycatch and entanglement in commercial fishing gear: lessons learnt and future directions
Fishing gear	Trawl and gillnet (also reviews a range of other fishing methods)
MM bycatch (test) species	ALL
Key finding	Successfully implemented mitigation measures include acoustic deterrent devices (pingers) which reduced the bycatch of some small cetacean species in gillnets. Substantial development and research of mitigation options is required to address the bycatch of a range of species in many fisheries. No reliably effective technical solutions to reduce small cetacean bycatch in trawl nets are available, although loud pingers have shown potential. Solutions are also needed for species, particularly pinnipeds and small cetaceans, that are not deterred by pingers and continue to be caught in static gillnets. Future mitigation development and deployment requires rigorous scientific testing to determine if significant bycatch reduction has been achieved, as well as consideration of potentially conflicting mitigation outcomes if multiple species are impacted by a fishery. Although outside the scope of this review, it was apparent that effective bycatch mitigation strategies often comprise a suite of management measures in conjunction with technical mitigation. These include traditional input and output controls, operational adjustments through 'codes of practice' protocols (e.g. 'move-on' provisions, handling, and release protocols) and implementation of appropriately designated spatial and/or temporal closures. Instigation of multi-jurisdictional agreements, regulations and/or legislation to facilitate mitigation implementation are also likely to be important (Geijer and Read 2013; Leaper and Calderan 2018).
Assumed causal agent for avoidance?	-Loud pingers '-a suite of management tools (along with pingers) reduces bycatch rates.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	NA
Caveats or uncertainties to methods	NA '-Distance from shore/depth considered?
Exhibited avoidance?	NA
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Successfully implemented mitigation measures include acoustic deterrent devices (pingers) which reduced the bycatch of some small cetacean species in gillnets. No reliably effective technical solutions to reduce small cetacean bycatch in trawl nets are available, although loud pingers have shown potential.
Application to NZ inshore fisheries	NA
Relevance to protected dolphin species assemblages in NZ	Discusses Hector's dolphin species. Includes references to relevant NZ papers (Dawson and Slooten 2005, Laverick et al. 2017)
Costs	Low
Benefits	Summarises all available literature to February 2019

Number	23
Reference	Hardy et al. 2012
Year	2012
Study name	An investigation of acoustic deterrent devices to reduce cetacean bycatch in an inshore set net fishery
Fishing gear	Demersal gill net, trammel net (tangle net)
MM bycatch (test) species	Harbour porpoise (Phocoena phocoena), Bottlenose dolphin (Delphinus delphis)
Key finding	Functioning pingers are likely to reduce harbour porpoise bycatch rates in this inshore tangle net fishery. Pingers resulted in a 35-51% decrease in harbour porpoise echolocation. Cycling pinger trials (static mooring), with a longer activity cycle, could identify recovery time, the possible effects of ambient noise, habituation, and the response of dolphins more accurately.
Assumed causal agent for avoidance?	-It has been a source of quite widespread concern that pingers might impede the movement of porpoises or exclude them from critical habitat. No evidence was seen of habituation to the pinger which is consistent with the findings of Palka (2008)
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low - moderate: Weight of evidence approach. Moderate click sample size, low level of static mooring sampling/testing effort, simplistic statistics. Reliance on fishermen to collect data. Not all variables managed or considered in statistics.
Caveats or uncertainties to methods	-Moderate sample size. Only four porpoise and no dolphin bycatches recorded. C-POD acoustic detectors used to passively assess the response of cetaceans to pingers. '-Each skipper was entirely responsible for deploying and recovering the equipment with their fishing gear while continuing with normal fishing activity in order to test the practical aspects of using pingers during normal working conditions. '- Some problems of tangling effecting fishing at the beginning of the trial. '-The placement of pingers on the footrope rather than the head rope of the set nets used in this trial has the following advantages: the head rope is not pulled down by the weight of the pinger; the pinger contributes usefully to the weight of the footrope; it may reduce the risk of 'button-holing' during deployment; and there is usually less tension on the footrope during hauling, putting less stress on the pinger. There has been concern that pingers on the bottom will be less audible to porpoises, but as these nets are deployed on a predominantly even seabed a major effect is unlikely.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Functioning pingers are likely to reduce bycatch rate in Harbour Porpoises
Application to NZ inshore fisheries	They are set for approximately five days 'soak time' depending on weather conditions at depths ranging from 20 to 100m. The fishery operates throughout the year.
Relevance to protected dolphin species assemblages in NZ	Similar inshore fishing depths
Costs	Concerns raised by the skippers taking part in the trial were mainly about the battery life of the pinger and the cost of putting them on all their fishing gear, rather than any other practical problems. These concerns were confirmed when pingers were recovered at the end of the trial and 7 out of 23 were found to be inactive, most likely due to flat batteries as no external damage was observed. Skippers found some difficulties in deploying the C-PODs on working nets because of their large size (90 800mm), but despite these difficulties they did obtain a substantial volume of useful data. The cycling pinger trial design used here proved to be an efficient and very low cost method of assessing responses to man-made sounds. Requires MM deaths to be able to determine success.
Benefits	Able to be performed on existing fisheries.

Number	24
Reference	Kastelein et al 2006
Year	2006
Study name	Differences in the response of a striped dolphin (Stenella coeruleoalba) and a harbour porpoise (Phocoena phocoena) to an acoustic alarm
Fishing gear	Gillnet discussed, but no nets used.
MM bycatch (test) species	A female striped dolphin (Stenella coeruleoalba) and a male harbour porpoise (Phocoena phocoena).
Key finding	"The porpoise reacted strongly to the alarm by swimming away from it and increasing his respiration rate. The striped dolphin, however, showed no reaction to the active alarm.
Assumed causal agent for avoidance?	It is difficult to determine whether differences in reaction to sound are due to hearing differences or differences in behaviour in relation to sound, unless two species have similar hearing. When audible, the SPL of a sound received by animals probably plays a role in whether sound is perceived as a threat or as an interesting novelty.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: small sample size, low level of sampling/testing effort, no statistical tests. Many uncontrolled variables.
Caveats or uncertainties to methods	-Sessions were not carried out during rainfall or when wind speeds were above force 4 on the Beaufort Scale. '-The present study was limited by animal welfare considerations. The animals were not exposed to the alarms' sounds for very long time periods to test potential habituation to the sounds, and the SL tested was limited by the maximum distance the animals could swim away from the alarms. '-Only one animal per species was available for the present study. It is not clear how representative each study animal was for its species. Age, sex, location, and experience may influence the behaviour of individuals. In addition, the two study animals may have influenced one another. Also, the fact that no effect of the alarm was seen in the striped dolphin does not mean that there was no effect, only that no effect was detected with the methods used in the present study. '-It is difficult to determine whether differences in reaction to sound are due to hearing differences or differences in behaviour in relation to sound, unless two species have similar hearing.
Exhibited avoidance?	Y: Harbour porpoise, N: Striped dolphin
Reduced bycatch?	NA
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	The porpoise in the present study reacted strongly to the alarm by swimming away from it and increasing his respiration rate. The striped dolphin, however, showed no reaction to the active alarm.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	The audiogram of the striped dolphin (Kastelein, Hagedoorn, Au, & de Haan, 2003) was of the animal in the present study, and is believed to be normal, as it resembles the audiogram of the bottlenose dolphin (Johnson, 1967). When audible, the SPL of a sound received by animals probably plays a role in whether sound is perceived as a threat or as an interesting novelty
Costs	The present study was limited by animal welfare considerations - requires captured animals to test.
Benefits	Able to be performed on captive MM.

Number	25
Reference	Kraus et al. 1997
Year	1997
Study name	Acoustic alarms reduce porpoise mortality
Fishing gear	Gillnet
MM bycatch (test) species	Harbour porpoise (Phocoena phocoena)
Key finding	The acoustic alarms reduced the incidental catch of harbour porpoises in sink gill-nets by an order of magnitude. Two harbour porpoises were captured in active strings and 25 in control strings. In six control strings, two porpoises were caught in the same string; in all other cases only, a single porpoise was taken. We captured similar quantities of two target species of the fishery in control and active strings, as well as other commercial species. Herring (no target species) were the only fish to show a significant difference in catch rate between active and control strings, with fewer herring taken in strings with active alarms. Clupeoid fishes have an unusual capacity for high-frequency hearing and it is possible that herring reacted to the alarms by avoiding the nets, thus reducing the number of porpoises becoming entangled while attempting to capture prey.
Assumed causal agent for avoidance?	Discusses: '-annoyance '-prey species avoidance
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low - moderate: Controlled experiment testing. Large sample size, multiple vessels, over only one season. Background ambient noise considered. Two harbour porpoises were captured in active strings and 25 in control strings.
Caveats or uncertainties to methods	Doesn't discuss background population level changes. Only one season of sampling. Doesn't discuss if outer environmental variables were controlled or investigated for correlations and significance. Unclear if there was variability between alarms outputs Article doesn't provide much detail on field methodologies or statistical methods used.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	The acoustic alarms reduced the incidental catch of harbour porpoises in sink gill-nets by an order of magnitude. Two harbour porpoises were captured in active strings and 25 in control strings. We captured similar quantities of two target species of the fishery in control and active strings, as well as other commercial species (thought there was a reduction in a non-target species (herring).
Application to NZ inshore fisheries	Acoustic alarms reduced the incidental catch of harbour porpoises in sink gill-nets by an order of magnitude
Relevance to protected dolphin species assemblages in NZ	The use of acoustic alarms would seem to be a promising method of reducing the number of harbour porpoises killed in sink gill-nets in the Gulf of Maine and offers hope for alleviating the bycatch problem for small cetaceans worldwide.
Costs	High cost - approximately US$500,000 (Figure obtained from Dawson et al 1998). Requires MM deaths to be able to determine success.
Benefits	Shows a dramatic improvement and is a rigorous study.

Number	26
Reference	Kyhn et al 2015
Year	2015
Study name	Pingers cause temporary habitat displacement in the harbour porpoise *Phocoena*
Fishing gear	Gillnet discussed; static mooring used
MM bycatch (test) species	Harbour porpoises (Phocoena phocoena)
Key finding	During the periodic-exposure scenario, the porpoise detection rate was reduced by 56% when pingers were active. The reduction was larger for the SaveWave pingers (65%) than for the Airmar pingers (40%). There was a tendency for the encounter rate to increase after the first 2−4 periodic exposures, which could indicate gradual habituation. During the continuous-exposure scenario, the detection rate was reduced by 65% throughout the 28 d with no sign of habituation. In the control areas (2.5, 3 and 5 km distant), neither a decrease nor an increase in detection rate was observed, suggesting that porpoises were displaced either <2.5 km or >5 km away. If pingers are used as deterrent devices, the impact of habitat exclusion must therefore be considered concurrently with mitigation of bycatch, especially when regulating fisheries in Marine Protected Areas.
Assumed causal agent for avoidance?	Both pinger types had a significant negative effect on the number of acoustic porpoise encounters. The encounter decrease was larger for the SaveWave pingers (65%) than the Airmar pingers (40%). The difference in deterrence effect is likely explained by the higher source level, more variable sounds and higher frequencies of the SaveWave pingers. The results of this study lend weight to the most parsimonious explanation, the deterrence hypothesis, rather than to the porpoises remaining silent in the area for several days followed by a gradual increase in echolocation rate.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low - moderate: Controlled experiment testing. Small sample size, different locations used, different spacing of pingers, pingers influencing each other. Good statistically modelling and probability methods. Great figure (Fig 2) that explain the porpoise encountered per month/treatment.
Caveats or uncertainties to methods	- not exclude that some individuals were exposed to the sounds several times and that these sounds were not associated with any negative reinforcement, indicates habitation. '-seasonal effects not considered. '-pingers influencing each other?
Exhibited avoidance?	Y
Reduced bycatch?	NA
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Both SaveWave and Airmar pingers effectively reduced harbour porpoise presence. However, exposure to the pingers led to a habitat displacement around each pinger site
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Exposure to the pingers led to a habitat displacement around each pinger site
Costs	Large amounts of pingers used. Moderately expensive.
Benefits	No MM deaths, mimics real fishing.

Number	27
Reference	Larsen et al. 2013
Year	2013
Study name	Determining optimal pinger spacing for harbour porpoise bycatch mitigation
Fishing gear	Gillnet
MM bycatch (test) species	Harbour porpoise (Phocoena phocoena)
Key finding	The results of the present trial support the argument that pingers are effective at longer ranges than the manufacturers' recommended spacings would suggest. When pingers were spaced 455 m apart, the harbour porpoise bycatch was reduced to 0, and even when spaced 585 m apart the bycatch was reduced to 22% of that in the control group of nets. The results presented in this report suggest that in the Danish hake gillnet fishery, the maximum spacing of AQUAmark100 pingers can be increased to at least 455 m without reducing their effectiveness. No statistical difference in target species catch, though limited data on this.
Assumed causal agent for avoidance?	Not discussed
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low - moderate: Controlled experiment testing. Relatively small sample size of one vessel, 5 fishing trips over 21 days, with a total of 108 hauls observed. A total of 50 porpoises were caught during the trial. Infers results to other Danish gillnet fisheries.
Caveats or uncertainties to methods	-Direction/methods of net setting? Most fleets were set east−west, but a few were set along bottom contours. '-Target species catches were only recorded for 27 hauls (12 without pingers, 14 with a pinger spacing of 455 m and 1 with a pinger spacing of 585 m). Consequently, only the mean catch rates for control nets and nets with 455 m spacing could be calculated and tested statistically for differences.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	When pingers were spaced 455 m apart, the harbour porpoise bycatch was reduced to 0, and even when spaced 585 m apart the bycatch was reduced to 22% of that in the control group of nets. No statistical difference in target species catch, though limited data on this
Application to NZ inshore fisheries	Depth not discussed
Relevance to protected dolphin species assemblages in NZ	Methods useful for testing NZ assemblages.
Costs	Moderate costs Requires MM deaths to be able to determine success.
Benefits	Able to be performed on existing fisheries.

Number	28
Reference	Leeney et al 2007
Year	2007
Study name	Effects of pingers on the behaviour of bottlenose dolphins
Fishing gear	Discusses gillnets, static mooring and boat-based trials used.
MM bycatch (test) species	Bottlenose dolphins (Tursiops truncatus)
Key finding	Both models of pinger tested in this preliminary study appear to have the potential to exert a displacement effect on bottlenose dolphins, but habituation may occur. In the static trials, overall detection rates of dolphin vocalizations on the T-POD were significantly lower in the presence of active CPs, but this was not the case for RPs. Mean inter-click interval values were longer for click trains produced in the presence of inactive RPs than for active RPs, active or inactive CPs. In boat-based trials, both active CPs and RPs appeared to affect bottlenose dolphin behaviour, whereby dolphins immediately left the area at speed and in a highly directional manner, involving frequent leaps.
Assumed causal agent for avoidance?	Not discussed
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: small sample size. Simplistic statistics. Many uncontrolled variables.
Caveats or uncertainties to methods	-In studying the behaviour of cetaceans from a survey vessel, it can be difficult to separate the effects of disturbance caused by the vessel itself, from other behaviours being observed in the field. '-small samples size. '-The lack of an evasive response, on two occasions, to active pingers is difficult to explain. It may be that the pingers failed to activate, or to elicit a response on these occasions. The use of a hydrophone in future trials would allow verification that pingers have indeed gone off and that the time of the alarm corresponds to the observed reactions of the dolphins. '-As this study was limited by time and funding, they were unable to carry out all possible pinger–T-POD-site combinations during the static mooring or boat-based trials. '-assumes vocalisation = dolphin presence, also assumes they are bottlenose dolphins.
Exhibited avoidance?	Y
Reduced bycatch?	NA
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	In the static trials, overall detection rates of dolphins were significantly lower in the presence of active continuous pingers, but this was not the case for responsive pingers. In boat-based trials, both active CPs and RPs appeared to deter bottlenose dolphins.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Bottlenose dolphin is in NZ also.
Costs	Low to moderate costs - study was limited by time and funding.
Benefits	The static mooring trials had the advantage of eliminating any effect boats may have on the behaviour of the dolphins; however, these fixed arrays had only limited access to dolphins. Boat-based trials offer the advantage of enabling dolphin groups to be actively located and record any immediate effect of pingers on dolphin behaviour. No MM deaths

Number	29
Reference	Maccarrone et al 2014
Year	2014
Study name	Economic Assessment of Dolphin Depredation Damages and Pinger Use in Artisanal Fisheries in the Archipelago of Egadi Islands (Sicily)
Fishing gear	Discusses artisanal fishing (long line, gillnet, and trammel nets) with small-size (<12 m) boats is mainly practiced, uses 2 experimental monofilament bottom gill nets.
MM bycatch (test) species	Bottlenose dolphins (Tursiops truncatus)
Key finding	Results have shown that, during the experimental fishing, the pinger net exhibited a production advantage compared with the control net, which improved the efficiency and effectiveness of the fishing activities. In addition, in 29 fishing days, the pinger net, based on the PPUE, reaches the production levels obtained with the control net five days in advance.
Assumed causal agent for avoidance?	Not discussed
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: small sample size. Simplistic statistics. Many uncontrolled variables.
Caveats or uncertainties to methods	-small sample size '-close proximity to an MPA (could influence MM results) '- designed as an economic evaluation of the pinger efficiency and the depredation phenomenon (rather than bycatch reduction)
Exhibited avoidance?	Y (depredation)
Reduced bycatch?	Y
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	During the experimental fishing, the pinger net exhibited a production advantage compared with the control net, which improved the efficiency and effectiveness of the fishing activities.
Application to NZ inshore fisheries	Rationale for fishers to use pingers
Relevance to protected dolphin species assemblages in NZ	Bottlenose dolphin is in NZ also.
Costs	Each pinger had a cost of 200 Euro. Could result in MM deaths to be able to determine success.
Benefits	Shows the economic benefits to mitigating against bycatch.

Number	30
Reference	Mackay and Knuckey 2013
Year	2013
Study name	Mitigation of marine mammal bycatch in gillnet fisheries using acoustic devices, literature review
Fishing gear	Shark gillnets operating under the Gillnet Hook and Trap Fishery
MM bycatch (test) species	Common dolphins (Delphinus delphis), bottlenose dolphins (Tursiops sp.).
Key finding	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. The spacing at which pingers are deployed along a net has been shown to affect the efficacy of reducing bycatch.
Assumed causal agent for avoidance?	Concerns of pinger use: Habituation (unlikely) habitat displacement (inconclusive) low compliance rates for pinger use = more bycatch.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	NA
Caveats or uncertainties to methods	-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. 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
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Some pinger varieties work for reducing common dolphin bycatch. Depredation on nets has been reduced from bottlenose dolphins using some varieties of pingers. Not clear if this relates to bycaught dolphins.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Bottlenose and common dolphins
Costs	Low cost
Benefits	Summarises all available literature to 2013

Number	31
Reference	Mangel et al 2013
Year	2013
Study name	Using pingers to reduce bycatch of small cetaceans in Peru's small-scale driftnet fishery
Fishing gear	Driftnet fishery
MM bycatch (test) species	Five species of small cetaceans were observed captured, including common dolphins (n=545), dusky dolphins *Lagenorhynchus obscurus* (n520), bottlenose dolphins (n525), Burmeister's porpoises *Phocoena spinipinnis* (n58) and pilot whales (n52).
Key finding	We have shown that pingers were effective at reducing bycatch of small cetaceans in the Peruvian small-scale driftnet shark fishery. Given the vast size of this fishery and its current levels of bycatch of small cetaceans (Alfaro-Shigueto et al., 2010; Mangel et al., 2010) appropriate use of pingers could result in mortality reductions of thousands of individuals per annum and would represent an important step for the conservation of small cetaceans in the south-eastern Pacific. There was no statistically significant difference in catch rates of sharks and rays, the primary target species in this fishery, between control and experimental sets
Assumed causal agent for avoidance?	How pingers work to reduce small cetacean captures in nets is still unclear.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Moderate: modelling and statistics, moderate sample size, obsolete pingers, but comparable to past studies.
Caveats or uncertainties to methods	-The urgent need to begin this research (because of high reported bycatch rates) and logistical constraints, meant that pingers available for the trial were limited, and were therefore spaced at 200 m intervals (more widely spaced than recommended) '-In addition to bycatch, 23 common dolphins and two dusky dolphins were observed to be harpooned, for use as bait on subsequent sets. Continued harpooning would offset some of the gains made through pinger use. '-seasonality?
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	Pingers reduced bycatch of small cetaceans in the Peruvian small-scale driftnet fishery. Most dramatically for the common dolphins. There was no statistically significant difference in catch rates of sharks and rays, the primary target species in this fishery, between control and experimental set
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	common dolphins, dusky dolphins, bottlenose dolphins and pilot whales also common in NZ
Costs	The current unit cost of commercially available pingers is c. USD 130 per unit and the recommended spacing is generally 200 m (Northridge et al., 2010). To equip a 2 km length net in this fishery would require an investment of c. USD 1,100–1,500. Requires MM deaths to be able to determine success.
Benefits	Able to be performed on existing fisheries. Accounts for a lot of variables in sampling protocol associated with fishing.

Number	32
Reference	McPherson 2011
Year	2011
Study name	Acoustic methods to mitigate bycatch and depredation by marine mammals on commercial fishing operations in Australian waters: Fishermen's options
Fishing gear	Various discussed, no nets used.
MM bycatch (test) species	Marine mammals
Key finding	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.
Assumed causal agent for avoidance?	NA
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Discusses the successes and failures of pinger investigations.
Caveats or uncertainties to methods	-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". At best, the simulated net 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.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	IND
Level of efficacy (reducing bycatch, maintaining target catch)	Supports pinger investigation.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	Low cost
Benefits	Summarises all available literature to 2011

Number	33
Reference	Northridge et al. 2010
Year	2010
Study name	Assessment of the impacts and utility of acoustic deterrent devices.
Fishing gear	Aquaculture
MM bycatch (test) species	Harbour porpoise (Phocoena phocoena)
Key finding	• Porpoises avoid areas where ADDs are active. • Porpoises return to areas almost immediately after ADDs are switched off. • Porpoises are not totally excluded from areas where ADDs are being used. • Porpoises were detected (feeding) even at about 200m from an Airmar ADD source. • Porpoises, dolphins and seals are most sensitive to the 10 kHz peak in the Airmar ADD signal. • ADD signals are not uniform. Acoustic signals from ADDs can be detected at more than 14km from the sound source. • Acoustic propagation losses are site specific and quite variable • Porpoises appeared to avoid one area where ADDs had recently been installed. • Porpoises appeared to be less averse to other areas where ADDs had been used for several years • Within the Sound of Mull, habitat modelling links porpoise distribution most closely to water depth and seabed slope, while ADD received levels were not a significant predictor of porpoise distribution.
Assumed causal agent for avoidance?	Annoyance avoidance
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low to moderate: Controlled experiment. Small sample sizes. Uses modelling and basic statistics, likely to have low statistical power though (not discussed)
Caveats or uncertainties to methods	-Difficult report to read, some uncertainty to level of sampling effort.
Exhibited avoidance?	Y
Reduced bycatch?	NA
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Porpoises avoid areas where ADDs are active
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	Moderate costs - similar to a static moored experiment
Benefits	Able to be performed at existing aquaculture sites. No MM deaths required.

Number	34
Reference	Northridge *et al.* 2011
Year	2011
Study name	Bycatch of Vulnerable Species: Understanding the Process and Mitigating the Impacts
Fishing gear	Static net fisheries (set nets, pair trawl)
MM bycatch (test) species	Harbour porpoise (Phocoena phocoena), Common dolphin (Delphinus delphis)
Key finding	Initial analyses suggest that Dolphin Dissuasive Devices (DDDs) may be heard 2km away while other pingers only reach 100-200m. Nets with DDDs caught significantly fewer porpoises (63-66%) but no significant difference in bycatch rate of dolphins. This reduction in porpoise bycatch is less than reductions reported for pingers (80-95%), however DDDs were more widely spaced. None of the bycatch in nets occurred within 1.2km from the nearest DDD. There is no significant difference in the observed bycatch rate of dolphins when DDDs are used with set nets, though sample numbers are too small to be confident that this reflects no real difference. It appears that dolphins bycatch rate reduced with use of DDD in a single paired trawl fishery, however pinger battery failure in 2010 meant that the data was not robust enough to test (also only one vessel pair investigated). DDDs appear to offer a viable and effective means of reducing porpoise bycatch in static net fisheries. We expect they will also result in reduced dolphin bycatch; however this has not yet been proven as current sample sizes are too small to provide statistically robust evidence. optimal positioning of DDDs inside the trawl and battery management to ensure that they continue to function correctly some evidence of decreased cetacean activity when a single DDD was in the water out to at least 1.2 km from the device and possibly as far as 3 km or more. The Aquamark appeared to have an effect up to about 400 m, though this particular result is preliminary pending further analysis. Other fleet characteristics (Net height and twine diameter), emerged from the analyses as being potentially more interesting in terms of developing bycatch mitigation measures. porpoise click frequency was similar at sites with a net present and at sites without a net, though there was a higher proportion of faster echolocation click-trains at sites with nets present, suggesting that either the nets provided an improved foraging area, or that the animals were actively examining the nets with their sonar. DDDs should not be used for longer than three seasons in this fishery (due to sealed battery degradation).
Assumed causal agent for avoidance?	- other fleet characteristics. '- pingers may have improved foraging area, or animals were examining the net with sonar
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low - moderate: small sample size, unbalanced design, interannual variables not controlled, high level of uncertainty/caveats.
Caveats or uncertainties to methods	-calculations were described in the paper as 'crude'. '-We caution that there are some extreme assumptions implicit in these calculations and that the exercise is most useful simply to highlight the fact that a 'mix and match' approach to pinger 6 deployment – by using different models and different spacings in different fleet segments can radically alter both the financial costs to the industry and the potential impacts in terms of habitat exclusion. '-Distance from shore/depth considered? '- The Aquamark appeared to have an effect up to about 400 m, though this particular result is preliminary pending further analysis. '-three seasons of data, but using different methods (2008 used multiple pinger/ 2009 & 2010 single pinger). '-some data collected by skippers rather than observers. '-The effects of DDDs on dolphin bycatch rates cannot yet be fully determined because we only observed 5 dolphin bycatches during the course of the trials. Continued monitoring will eventually clarify this point. The closest dolphin bycatch event was 1.3 km from a DDD. '-Some vessels outside the normal foraging depth range of most small cetaceans. '- One skipper thinks that when bycatch does occur the animals are caught as the gear is being shot, rather than when the net is lying on the seabed, and suggested that a more sensible approach for this fleet might involve having a powerful pinger attached to the boat to deter animals from the vicinity during shooting operations. '-No consideration of target fish or species caught when bycatch event occurred. '-Historic batch catch data not compared. '-Different pingers used in the bass fishery study. Only two vessels consistent vessels over time. 'pingers deployed at different depths '-A number of hauls recorded in the observer database contained missing values (for looking at other fishing related factors to bycatch events) - data was extrapolated from past data (to use in the model).
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Reduces porpoise bycatch, but not clear if it reduces dolphin bycatch.

Application to NZ inshore fisheries	Distance from shore/depth did not appear to have been considered so not sure if relevant to NZ conditions.
Relevance to protected dolphin species assemblages in NZ	Common dolphin is in NZ also.
Costs	We also calculated the likely financial costs to the relevant vessels, firstly if only the >12m vessels were to use pingers, and also if each of three other size categories of vessel (10-12m, 8-10m and <8m) were also required to use pingers at some point in the future. The total costs ranged from roughly £113,000 to over £2.5 million, depending on the pinger model used and the spacing chosen. Pingers can damage nets. Liable to malfunction/break frequently. Requires MM deaths to be able to determine success.
Benefits	Although these devices are known to be effective at minimising porpoise bycatch, they are not always practical to use (SMRU et al. 2001a). Trials by Seafish (Anonymous 2003; Anonymous 2005) in the UK and similar trials conducted by the relevant authorities in Ireland and France (Cosgrove, Browne & Robson 2005; Le Berre 2005) have shown that none of the devices described by the regulation are suitable for fisheries that use long fleets of gill or tangle nets. High levels of damage to and loss of pingers was reported, as were potential dangers to crew members when devices broke during deployment or retrieval.

Number	35
Reference	Orphanidea and Palka 2013
Year	2013
Study name	Analysis of harbour porpoise gillnet bycatch, compliance, and enforcement trends in the US north-western Atlantic, January 1999 to May 2010
Fishing gear	Gillnets
MM bycatch (test) species	Harbour porpoise (Phocoena phocoena)
Key finding	Changes in fishing effort and distribution of key fisheries played a large role in decreasing the bycatch in much of the Mid-Atlantic and also in increasing bycatch in Southern New England and off the coast of New Jersey. The pattern in compliance levels had an inverse relationship with bycatch levels, with better compliance and lower bycatch in early and late years, though compliance was generally poor even when at its best. Given poor compliance with pinger requirements, these requirements have not resulted in the expected reduction in bycatch.
Assumed causal agent for avoidance?	Not discussed
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: sample size not defined but appears large. Simplistic statistics. Significant uncontrolled variables.
Caveats or uncertainties to methods	-Even though the pinger functionality sample size from 1999 to 2010 is relatively small, the data suggest that even when the proper number of pingers was used, they may not have all been functional. This makes estimating true compliance (when all pingers were functional and also present in the required numbers) challenging. It also makes it difficult to quantify the effectiveness of pingers in reducing bycatch. '-estimating bycatch for the Mid-Atlantic is challenging because it is on the southern end of the harbour porpoise range, and, thus, bycatch can vary substantially between seasons and years, depending on the extent to which harbour porpoise occupy the area. '-inter-annual variability, both in the Mid-Atlantic and in New England, may have been related to natural variability of environmental factors associated with harbour porpoise distribution.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA - discussed how targeted fish effects the bycatch rate.
Level of efficacy (reducing bycatch, maintaining target catch)	This review suggests that pingers are still an effective way to deter harbour porpoise bycatch, though they will have a reduced effect if they are not all working and are not present in the required numbers. This review suggests that, for pinger management actions to be effective, steps must be taken to ensure compliance with the management actions
Application to NZ inshore fisheries	Relevant for designing a NZ experiment and management
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment and managing pinger use.
Costs	Low cost
Benefits	Uses existing data.

Number	36
Reference	Palka et al. 2008
Year	2008
Study name	Effect of pingers on harbour porpoise (Phocoena phocoena) bycatch in the US Northeast gillnet fishery
Fishing gear	Not specified but mostly sink gill nets in area
MM bycatch (test) species	Harbour porpoise (Phocoena phocoena)
Key finding	Bycatch rates in hauls without pingers were greater than those with the required pingers. Unexpectedly, when hauls had an incomplete set of pingers, bycatch was greater than those without pingers altogether. As mesh size increased so did bycatch rate, despite the presence of pingers. All observed bycatch was in nets of >15 cm mesh size. No evidence of temporal trends in bycatch, suggesting no habitation so far.
Assumed causal agent for avoidance?	The increased bycatch in hauls with incomplete pingers could be due to several potential confounding factors. By chance, there may have been different environmental/gear characteristics. Harbour porpoise may interpret a gap in pingers as a gap in the net.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Moderate: modelling and statistics, large sample size, comparable to past studies.
Caveats or uncertainties to methods	-environmental factors and mesh size appear to influence the bycatch rate, in addition to the use of pingers.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	IND
Level of efficacy (reducing bycatch, maintaining target catch)	Support that pingers can reduce harbour porpoise bycatch, even in an operational fishery. Uses fishing effort as a proxy for target catch rates, but not clear if this was maintained or not.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	High cost
Benefits	Able to be performed on existing fisheries.

Number	37
Reference	Petras 2003
Year	2003
Study name	A Review of Marine Mammal Deterrents and Their Possible Applications to Limit Killer Whale (Orcinus orca) Predation on Steller Sea Lions (*Eumetopias jubatus*)
Fishing gear	Briefly discusses gillnets, longline depredation, and aquaculture sites, as well as minimising predation in migrating salmon.
MM bycatch (test) species	NA
Key finding	Based upon a thorough review of the literature, lack of previous long-term success and high degrees of uncertainty, it is unlikely that deterrents would be successful in this application. The standard pinger emits a signal of 10 kHz (with harmonics to at least 60 kHz) with a source level of 132 dB re 1 micro Pascal at 1 m, which is within the hearing range of most cetaceans and pinnipeds (Reeves et al. 1996). Different pingers can emit sounds differently, with regular pulse intervals, random intervals or frequency sweeps (Cox et al. 2001). Most experiments to test the effectiveness of pingers have been done with porpoise interacting with gillnet fisheries and have shown them to be generally effective in reducing porpoise bycatch (Hatakeyama et al. 1994, Gearin et al. 2000, Kraus et al. 1997, Culik et al. 2001). Though, there is evidence that porpoise may habituate to pingers (Cox et al. 2001) suggesting that variable sounds and monitoring are important to maintaining effectiveness (Kastelein et al. 2000). Tests done in the field showed that while harbour porpoise avoided nets equipped with pingers, they approached and became entangled in, unequipped nets 100 – 200 m away (Trippel et al. 1999). Incorporating time and area closures may also be important to reducing porpoise bycatch (Murray et al. 2000). It's still unclear if the pinger sound serves to alert the marine mammals to the presence of the net, or if the sound may simply be annoying to the animal and therefore repel it from the area, or if the sound may be aversive to the prey of marine mammals (IWC 2000, Krause et al. 1997). Based on the relatively few rigorous studies, it appears most likely that pingers work with porpoise through aversion (IWC 2000). Where the pingers may cause an aversion response in the prey of porpoise such as herring that have unusually high hearing sensitivity (Nestler et al. 1992). The porpoise may move in response to movements in their prey and thus avoid nets (Dawson et al. 1998). Hector's dolphins (*Cephalorhynchus hectori*) were most consistently deterred with a pinger with pulse lengths of 400 milliseconds and fundamental frequency at approximately 9.6 kHz with strong harmonics up to, and probably over, 150 kHz, although other pingers were reported to be ineffective (Stone et al. 2000). Other experiments indicated no significant deterrence of dolphins in response to pingers (Reeves et al. 2001). Different species of marine mammals respond differently to ADDs. Despite years of trials, more experiments are needed to better understand the effectiveness and possible impacts of ADDs. One issue of particular concern with ADDs is the exclusion of marine mammals from areas where they typically forage (Dawson et al. 1998, IWC 2000).
Assumed causal agent for avoidance?	-Alerts to the presence of the net, '-the sound may be annoying to the animal and therefore repel it '-the sound may be aversive to the prey of marine mammals (reducing foraging) '-may affect (mask) an animal's echolocation, stimulating the porpoise to echolocate more and detect the net. '-pingers + management tools might be the reason they are effective/not effective. '-need variable sounds and monitoring to maintain effectiveness (they get used to the sound). '-species '-need to consider all variables: The received level of sound is dependent upon the effects of spherical and cylindrical spreading, water depth, and absorption (Johnston and Woodley 1998) as well as water temperature, salinity, and movement (i.e., tides and waves) (Reeves et al. 1996). Weather and ambient noise including anthropogenic and biological sounds also have an effect (Erbe and Farmer 2000).
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	NA
Caveats or uncertainties to methods	Not clear if the author thinks ADDs create sonar scrambling or effect predation/foraging? Some contradictory statements…. Between last paragraph on page 11 and 2nd paragraph page 10. The need for research on the basic life history, ecology, abundance, and distribution of transient killer whales is important for determining the possible impacts
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	generally effective in reducing porpoise bycatch
Application to NZ inshore fisheries	NA
Relevance to protected dolphin species assemblages in NZ	Refers to Hector's dolphin

Costs	NA
Benefits	NA

Number	38
Reference	Shapiro et al 2009
Year	2009
Study name	Transmission loss patterns from acoustic harassment and deterrent devices do not always follow geometrical spreading predictions
Fishing gear	Not specified
MM bycatch (test) species	Marine mammals
Key finding	Superimposed onto an overall trend of decreasing sound exposure levels with increasing range were large local variations in the sound level for all sources in each of the environments. Animals may encounter difficulties when trying to determine the direction to and location of a sound source, which may complicate or jeopardize avoidance responses. e.g. a steadily reliable decrease with increasing range would not occur since the levels fluctuate dramatically. The variability in the sound exposure level (SEL) may be an important factor to consider when evaluating the implementation of acoustic mitigation devices in fishery regimes.
Assumed causal agent for avoidance?	Pain or annoyance
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: sample timing over the day not described but appear to have tested each pinger type at each location. Simplistic statistics.
Caveats or uncertainties to methods	-probability/significance or correlations are not provided. '-sample timing over the day not described
Exhibited avoidance?	Y (site specific)
Reduced bycatch?	NA
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	The success of pingers at deterring MM likely depends on how the signal propagates in a coastal environment, which appears to be a lot more variable than previously assumed.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment and management
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment and managing pinger use.
Costs	Low cost, minimal field days and modelling.
Benefits	Able to be performed at multiple locations/environments to estimate the efficacy of pingers. No MM deaths required.

Number	39
Reference	Soto et al. 2013
Year	2013
Study name	Acoustic alarms elicit only subtle responses in the behaviour of tropical coastal dolphins in Queensland, Australia
Fishing gear	Discusses gillnets, vessel mounted pinger used.
MM bycatch (test) species	Australian snubfin dolphin (Orcaella heinsohni), Indo-Pacific humpback dolphin (Sousa chinensis)
Key finding	The movements and behaviour of both species changed subtly when the pingers were active, but the likelihood of the animals leaving an area was not significantly different from the controls. Our results suggest that this technological approach may not be effective in reducing the bycatch of these species. We suggest that further experimentation is unlikely to be cost effective and that government agencies should work with fishers and scientists to explore alternative mitigation measures. Snubfin dolphins slightly decreased the time they spent vocalising, while humpback dolphins slightly decreased the time they spend foraging and their rates of both active surfacing and clicks. These changes occurred once the pinger was introduced and remained after it was removed.
Assumed causal agent for avoidance?	This reaction may be a component of an alertness response, in which the animal reduces vocalisation to better listen for the acoustic source. Animals may reduce echolocation rates and time vocalising as a response to perceived danger, to reduce e.g. predation risk, although doing so may increase the likelihood of a potential entanglement.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low to moderate: Controlled experiment. Small sample sizes. Good statistical explanations, likely to have low statistical power though (not discussed)
Caveats or uncertainties to methods	-not mimicking a real fishery (no net used). '-Calculating the sound propagation of acoustic alarms and deterrents is extremely complex, as the sound field is highly dependent on factors such as habitat morphology and depth of source and receiver. '-We assumed Baldwin's (2002) estimates of pinger propagation in a shallow silty-clay environment (60 m) to be a reasonable approximation of the sound field for the Fumunda pinger in Keppel Bay, an environment similar to the Hinchinbrook region. This assumption was not tested empirically. '-The duration of each treatment was 10 min for humpback dolphins and 5 min for snub - fin dolphins. This difference reflected the difficulties in approaching the elusive snubfin dolphins. '-treatments used 1 to 3 pingers only. '-thousands of trials would be required to have the power to detect a significant result for Queensland populations of humpback and snubfin dolphins. '-one site lacked a high observation point from which to take long-distance readings through traditional theodolite tracking such as that conducted by Cox et al. (2004). '-Snubfin dolphins were much more difficult to find and observe than humpback dolphins '-Pingers were tested from a research vessel. The presence of the vessel may have affected results, compared with testing on independent nets.
Exhibited avoidance?	N
Reduced bycatch?	N
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	Pingers not considered effective. 10 kHz frequency acoustic alarms should not be implemented to reduce MM bycatch in coastal Queensland waters. Funding would be better spent working with fishers and scientists to develop practical solutions to this bycatch problem, rather than conducting further trials of technology-based solutions such as pingers.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	A comprehensive study of the efficacy of acoustic alarms to reduce bycatch in Queensland would require a significant number of pinger types to be tested in a range of different inshore habitats across all marine mammals of conservation concern. Our research took over 300 h of fieldwork to complete tests for only 1 pinger type and 2 species of dolphins. Assuming 10 types of acoustic alarms, we estimate that it could take up to 3000 h to test them all, costing millions of dollars in labour, equipment and transport, and the active collaboration of the commercial gillnetting industry for extensive periods of testing. Even if some pingers were found to be effective in reducing dolphin bycatch and their use were mandated, the required enforcement would be extremely expensive for a relative low-value fishery worth \$20 to \$30 million USD yr−1 (Department of Primary Industries & Fisheries QLD 2006), especially as this fishery operates largely from small boats in remote areas with few observers.
Benefits	No MM deaths, lower cost than real fishing.

Number	40
Reference	Stone *et al.* 2000
Year	2000
Study name	Reactions of Hector's dolphins to three acoustic gillnet pingers
Fishing gear	Gill net
MM bycatch (test) species	Hector's dolphin *(Cephalorhynchus hectori)*
Key finding	Dolphins generally avoided pingers (though significance not tested). The White Dukane ® Pinger with steady evenly spaced harmonic peaks at approximately 10, 40 60, 80, 100, 110, 130, 150 kHz was significantly more effective than the Black Pice ® Pinger, and the Red Dukane ® Pinger at deterring dolphin groups. No change in echolocation under the four conditions, indicating that avoidance of pingers may not be related to the echolocation habits of the dolphins (or that pingers do not interfere with dolphin echolocation)
Assumed causal agent for avoidance?	-Avoidance. '-pingers do not appear to interfere with dolphin echolocation
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low - moderate: simplistic statistics, missing some probability analysis, high level of uncertainty/caveats.
Caveats or uncertainties to methods	-Used from vessel (attracts dolphins?). '-No gillnets used, so no way to determine how the pinger + net might change behaviour. '-Only performed in fine/calm weather (very wind affected). '-Akaroa dolphins mix groups, possible repeat exposure to some group members. '-Click only detectable 10-25m (estimated) from the hydrophone. '-Difficult to determine the direction of the dolphins clicks, except by observation of the head orientation. '-Does not consider cumulative noise effects (resonant frequency with surrounding ambient noises). '-Doesn't mention at what level of thermocline would it start to isolate the pinger sounds? '-Sea temperature profiles were only done on two days in January, during summer. '-Clicks per dolphin were calculated by dividing the total number of recorded clicks by the number of dolphins in the group, and assumes all dolphins are producing clicks evenly (see footnote, Table 4). '-The summary says the avoidance behaviour was significantly higher using the White Dukane Pinger, however there was no actual P values provided (it incorrectly refers to Figure 5 for 'significance' information). '-undefined error bars in Figure 6. '-Only one type of each variety of pinger was tested, so instrumentation variability wasn't able to be taken into consideration. '-Akaroa dolphins are accustomed to set nets. '-Distance from shore/depth considered? '-doesn't consider spacing of pingers/or multiple pingers being used on nets.
Exhibited avoidance?	Y
Reduced bycatch?	NA
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	63% of dolphin groups (21/32 events) exhibited avoidance when the white pinger was in the water. No nets used in the study so no information relating to reductions in bycatch and maintenance of target species.
Application to NZ inshore fisheries	Low (region specific)
Relevance to protected dolphin species assemblages in NZ	Investigates native, endangered Hector's dolphin species to NZ
Costs	Moderate - high: 19 attempted days using multiple staff, a vessel + hydrophone and computing software. Data analyses in Australia. Est $6000 per day = $114,000
Benefits	Local, investigates taxa of concern.

Number	41
Reference	Teilmann et al 2006
Year	2006
Study name	Reactions of captive Harbour Porpoises (Phocoena phocoena) to pinger-like sounds
Fishing gear	Discusses gillnets, pinger tested on confined porpoises.
MM bycatch (test) species	Harbour porpoise (Phocoena phocoena)
Key finding	The animals responded most strongly to the initial presentations of a sound. Surface time decreased, the heart rate dropped below the normal bradycardia, and echolocation activity decreased. The reactions of both animals diminished rapidly in the following sessions. Should the waning of responsiveness apply to wild animals, porpoises may adapt to the sounds but still avoid nets, or the bycatch may increase after some time. The success of long-term use of pingers may then depend on the variety of sounds and rates of exposure.
Assumed causal agent for avoidance?	Annoyance avoidance
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Low: Small sample sizes. Uses basic statistics, with uncertainties and test violations, likely to have low statistical power though (not discussed)
Caveats or uncertainties to methods	-Ten to 15 min before each session the dorsal pack was placed on the female (none on the male). The dorsal pack had an effect on the behaviour of the female. '- An important prerequisite for the X2 test is violated. As each of the individual observations (the sector in which the animal was in a given second) was, without doubt, strongly influenced by where the animal was in the previous second. Thus, the observations were not independent. This, however, does not prohibit the use of theX2 statistic as a relative measure of difference between the mean pre-sound period and individual sound periods. '-The bimodal nature of marine mammal heart rate (tachycardia/bradycardia) also makes it difficult to estimate average values. '- measures of average distance to the sound source to quantify avoidance reactions, is probably a more accurate measure of displacement than the X2 statistic used in the present study. '-because of the narrow-beam nature of the harbour porpoise sonar, a complete record of echolocation activity can never be recorded by poolside hydrophones. '-The two captive harbour porpoises were used in earlier studies to evaluate the effects of aversive pinger-like sounds, which may have influenced the magnitude of responses we report here. '- there were limitations on pool size and depth, as well as external noise from harbour traffic—mostly small, diesel driven fishing vessels and small boats with outboard motors—potentially influenced the results. '-caution is required when extrapolating our results to a natural situation or to experiments performed in other facilities.
Exhibited avoidance?	Y
Reduced bycatch?	NA
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	the general aversive response of harbour porpoises to acoustic stimuli is to swim away from the sound source, spend less time at the surface, increase acceleration, deepen the bradycardia below normal, and reduce echolocation in the vicinity of the sound source.
Application to NZ inshore fisheries	Relevant for designing a NZ experiment
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	High costs, requires live captured MM. Many variables to control.
Benefits	No MM deaths, perhaps lower cost than real fishing examples. Can more easily determine behavioural reactions.

Number	42
Reference	Teilmann et al 2015
Year	2015
Study name	Porpoise monitoring in pinger-net fishery. Final baseline report.
Fishing gear	Discusses gillnets, collects baseline data.
MM bycatch (test) species	Harbour porpoise (Phocoena phocoena)
Key finding	The four years of data collected so far constitutes a baseline for assessing the potential effect of employing pingers in the impact area. Power analysis show that the current baseline data and a continuation of the monitoring program during the employment of pingers for one year, would allow for detecting relative changes of density (PPM) around 22% and echolocation behaviour (CPPM) around 42%. If monitoring continues for up to four years the relative changes that can be detected is reduced gradually to 14% and 25%, respectively.
Assumed causal agent for avoidance?	NA
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	High: addresses seasonal effect, determines effect size before using pingers, characterises background variables.
Caveats or uncertainties to methods	-BACI design, where the implicit assumption is that the porpoise detection activity in the control and the impact area are essentially governed by the same mechanisms over time, such that a potential effect of using pingers can be traced as a deviation in the impact area compared to the control area after the pingers have been employed.
Exhibited avoidance?	NA
Reduced bycatch?	NA
Maintained target catch	NA
Level of efficacy (reducing bycatch, maintaining target catch)	NA
Application to NZ inshore fisheries	Relevant for designing a NZ experiment / provides background information on species behaviour and distribution required before pinger use can be tested.
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment
Costs	High costs - 4 years baseline + 14 cPODs used.
Benefits	No MM deaths, perhaps lower cost than real fishing examples. Can more easily determine behavioural reactions.

Number	43
Reference	Waples et al. 2013
Year	2013
Study name	A field test of acoustic deterrent devices used to reduce interactions between bottlenose dolphins and a coastal gillnet fishery
Fishing gear	Demersal gillnet
MM bycatch (test) species	Bottlenose dolphin (Tursiops truncatus)
Key finding	Fish catch was significantly lower when dolphin interactions were observed. Pingers did not affect fish catch, but dolphin interaction decreased, and echolocation increased with active pingers. The durability of pingers however, is not sufficient for effective deployment in this fishery.
Assumed causal agent for avoidance?	We conclude that dolphins used echolocation to investigate the nets equipped with active SaveWave devices, which would enhance their ability to detect and avoid these nets.
Level of scientific rigor (dark green = high rigor, dark red= low rigor)	Moderate: reasonable modelling and statistics, moderate fishing set sample size (though low for focal follows), testing carried out over same season (summer) each year, some uncertainties.
Caveats or uncertainties to methods	-Number of focal dolphin follows is fairly low. Dolphin depredation of catch not observed often enough to determine whether pinger use affects depredation rates. '-Not blind tested. The fishermen were not informed whether active or control alarms were to be used, but once the devices were deployed on the first set and the saltwater switches were activated, the devices with white cores were audible. '-observations didn't use a theodolite. '-pingers not deployed in 2003. '-inter-annual variation in frequency of depredation, population changes need to be considered for interannual investigations.
Exhibited avoidance?	Y
Reduced bycatch?	Y
Maintained target catch	Y
Level of efficacy (reducing bycatch, maintaining target catch)	SaveWaves were effective in deterring dolphins from interacting with Spanish mackerel gillnets, although our observations from the research vessel indicate that the ADDs did not eliminate this behaviour entirely. Pingers did not affect fish catch, but dolphin interaction decreased, and echolocation increased with active pingers
Application to NZ inshore fisheries	Relevant for designing a NZ experiment - though difficult to do follow observations from shore in NZ.
Relevance to protected dolphin species assemblages in NZ	Relevant for designing a NZ experiment Bottlenose dolphin is in NZ also.
Costs	The SaveWave devices were not sufficiently physically robust to be used effectively in the Spanish mackerel gillnet fishery, where gear is deployed and retrieved with a hydraulic net reel system. When the fishermen attempted to wind nets onto their reels with the SaveWaves attached, the device housings cracked under the weight and tension of the nets. Fishermen instead had to attach and remove the devices by hand each time a net was deployed or retrieved, which proved to be very time consuming.
Benefits	Able to be performed on existing fisheries. High depredation levels but low bycatch rates (no dolphins caught during study).