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**REVIEW OF METHODS USED TO REDUCE RISKS OF CETACEAN BYCATCH
AND ENTANGLEMENTS**

Summary:

This Review of Methods Used to Reduce Risks of Cetacean Bycatch and Entanglements has been financed by the World Wildlife Fund (WWF) specifically with the intention to support initiatives to address cetacean bycatch, including those by CMS, its associated regional agreements, ASCOBANS and ACCOBAMS, and the IWC. It provides a summary of the current state of mitigation techniques.

The CMS Secretariat and experts associated with the Scientific Council have had opportunity to peer review the report, ensuring its relevance to the work of the Convention.

REVIEW OF METHODS USED TO REDUCE RISKS OF CETACEAN BYCATCH AND ENTANGLEMENTS

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ABSTRACT

Fisheries bycatch is considered to be the greatest threat to cetaceans globally. From coastal artisanal fisheries to deep-sea industrial operations, incidental capture of whales, dolphins and porpoises in a range of fishing gear has resulted in serious welfare and conservation issues for many cetacean species, sometimes to the point of regional extinction. Whilst there has been concern about bycatch for several decades and attempts to find solutions, progress has been limited. Through the use of case studies, this report summarises the mitigation methods that have been undertaken with the objective of reducing cetacean bycatch, and assesses their efficacy and future potential. These include methods for reducing risk of contact between cetaceans and fishing gear, such as effort reduction, fishing bans and gear modifications, together with methods for reducing harm should entanglement occur. This review is intended to support initiatives to address cetacean bycatch, including those by CMS, its associated regional agreements, ASCOBANS and ACCOBAMS, and the IWC, by providing a summary of the current state of mitigation techniques. The review focusses on specific technical measures but these need to be considered as part of overall strategies involving all stakeholders. There are rather few examples of implemented mitigation measures substantially reducing cetacean bycatch. Enforcement and compliance are key to the success of any measures, and the lack thereof has been the cause of many mitigation programmes' failure to meet their objectives. Generally, mitigating cetacean bycatch has not been viewed as intrinsic to successful fisheries management, but rather as a separate management issue. However, where reductions in bycatch have occurred, a feature of these situations has often been that a systemic change in the fishery itself has resulted in reduced cetacean bycatch, rather than the success of any mitigation measures specifically imposed for cetaceans. Given the pressing need for improvements in fisheries management globally, reduction of cetacean bycatch should be seen as a key part of such initiatives. The most generally effective mitigation of cetacean bycatch and entanglement is reduction in effort, starting with those fisheries that have the largest bycatch.

1. INTRODUCTION

Cetacean bycatch is characterised globally by a deficiency of data on fisheries effort, abundance estimates and bycatch mortality, and it is often not possible to assess the impact of bycatch-related mortality on cetacean populations. However, wherever studies are conducted, large numbers of small cetaceans are found to be affected by bycatch (Young and Iudicello 2007). According to the U.S. Ocean Commission, bycatch is the 'biggest threat to marine mammals worldwide . . . [killing] hundreds of thousands of them each year' (U S Commission on Ocean Policy 2004, Read et al. 2006). 82% of odontocete species have been recorded as bycatch since 1990; 75% have been caught in gillnets (Reeves et al. 2013).

Small cetaceans (chiefly dolphins and porpoises) most commonly become entangled in gillnets, both set and drifting, but also in purse seines, trawls, long lines and traps, which are designed to target species which are often of similar size to dolphins and porpoises (Read 2013, Reeves et al. 2013). Species which inhabit coastal and shelf waters are especially vulnerable, as are species in developing countries, where fisheries management is often lacking, and small-scale artisanal as well as large industrial fisheries can cause high levels of mortality (Dawson and Slooten 1993, Young and Iudicello 2007, Reeves et al. 2013).

Large whales can become entangled in nets or just about any form of line in the water. This includes many types of fishing gear but also some aquaculture and mooring lines. Large whale entanglements are rarely observed directly and entanglement events are considerably underreported for most populations and regions (IWC 2010). Nevertheless entanglement is known to be the major source of mortality for several populations (Thomas et al. 2016).

Cetacean bycatch increased dramatically with the proliferation of monofilament gillnets in the late 1960s (e.g. Slooten (2013)). Waugh et al. (2011) highlight how in the last two decades, the increasing use of outboard motors in many artisanal fisheries has potentially greatly increased fishing effort in this sector (including the geographical extent of that effort) with a likely associated increase in bycatch.

Bycatch and entanglements are not just a problem for the cetaceans involved, both from conservation and welfare perspectives (Moore and Van der Hoop 2012, Papastavrou et al. 2017). Lost or damaged gear carries a high economic cost. Dealing with carcasses or live animals can also be time consuming, expensive and dangerous for fishers and rescuers.

1.1 International agreements and efforts on mitigation

There have been a large number of reviews of mitigation methods (e.g. Werner et al. (2006)) and continuing discussions within all the relevant international fora. In particular, IWC, CMS and its associated regional agreements ASCOBANS and ACCOBAMS, and ICES all have ongoing work programmes related to bycatch. In addition there have been many national initiatives, regional workshops (see IWC (2016)) and collaborations.

Decisions by international bodies in 2016 demonstrate a renewed commitment to addressing cetacean bycatch. These include a new bycatch initiative by IWC, Resolution 5 at the 8th Meeting of parties to ASCOBANS, proposals to establish a joint ASCOBANS/ACCOBAMS bycatch working group and new regulations from the US to restrict seafood imports. The Marine Mammal Protection Act of the US requires specific measures in US fisheries to protect cetaceans from bycatch. The US recently announced measures on seafood imports into the US which will require comparable measures to address bycatch for any fishery exporting to the US (Federal-Register 2016, Williams et al. 2016). ASCOBANS Resolution 8.5 calls for appropriate technical and other measures to mitigate cetacean bycatch to be developed, implemented and evaluated.

This review is intended to support these initiatives by providing a summary of the current state of mitigation techniques illustrated by a number of case studies.

1.2 Terminology

This report reviews methods to reduce risks of cetacean entanglement and bycatch in fishing gear, but there is no fundamental distinction between the two. Following discussions at IWC Scientific Committee (IWC 2016) , the term ‘entanglement’ is used within this report in line with the definition in IWC (2010) that entanglement involves the presence of line, netting, or other materials wrapped around body areas of a whale and may include cases in which animals are towing gear or anchored by gear. The term ‘bycatch’ is used in a wider sense but generally involves a fatal interaction between a cetacean and fishing gear.

Management of activities that affect cetaceans is often divided between small cetaceans and large whales. Sometimes the division between small cetaceans and whales can be somewhat arbitrary. From the perspective of bycatch and entanglement a division between smaller and larger animals

based on body mass and swimming power does make a considerable difference. Propulsive power has been examined in detail in bottlenose dolphins (e.g. Fish et al. (2014)) and inferred across a range of species suggesting propulsive power (P) as a function of body length (L) where $P = L^{1.56}$ (Arthur et al. 2015). Based on these results, a 20m baleen whale will likely generate around 60 times the propulsive power of a 1.5m porpoise. Such differences in power and body mass, which could differ by a factor of 1000, will clearly result in very different interactions with fishing gear. Smaller cetaceans are often similar size and body mass to the target catch species whereas large whales are often powerful enough to transport fishing gear over large distances.

Fishing gear can be roughly divided into three categories: actively fished, wet storage when gear is left in the water but is not actively fished (e.g. unbaited traps), and lost or discarded. Lost or discarded gear can be regarded as marine debris which can also include non-fishing related items that pose an entanglement risk. Wet storage can occur for a number of reasons due to difficulties of transporting at sea or storing ashore, but gear may also be set just to 'protect a patch' (i.e. preserve an individual's use of an area). If there is any intention to retrieve it then such fishing gear is not covered by MARPOL. In the context of MARPOL Annex V, fishing gear that is released into the water with the intention for later retrieval, such as fish aggregating devices (FADs), traps and static nets, should not be considered garbage or accidental loss (IMO 2012).

1.3 Evaluation of the effectiveness of mitigation

In some areas considerable efforts are put into assessing bycatch in terms of the conservation implications of the number of animals removed in relation to the estimated population size. However, data are lacking in many areas and even where much work has been put into monitoring bycatch, it is often not possible to estimate the total bycatch mortality for a population with a high degree of precision or accuracy (e.g. ICES (2016)). Observer and monitoring schemes are important to address such data gaps (Reeves et al. 2013). However it is also reasonable to assume that where fisheries coincide with coastally-distributed cetaceans, bycatch, however poorly documented, will occur. Mitigation options can therefore be considered, implemented and evaluated based on estimates of expected risk and risk reduction, rather than waiting for data which might never be forthcoming. Compared to large whales, small cetaceans can be relatively numerous, and bycatch events more frequent. Therefore sample sizes may be larger, providing greater potential to evaluate the effectiveness of mitigation measures and detect changes in entanglement rates in response to management measures. In addition, most small cetaceans are found dead in the gear where it has been deployed, whereas large whales are powerful enough to swim away, even though entangled in gear and often with poor long-term survival prospects.

Evaluating the effectiveness of any measures that are taken for large whales has proven especially difficult. Large whales that are not subject to anthropogenic impacts have high natural survival rates, and so even rare incidents of entanglement deaths can influence population dynamics. However, changes in entanglement rates can be hard to detect due to the small sample sizes of reported incidents. Even in one of the most intensively monitored areas off the New England region of the USA it has not been possible to determine, based on the number of annual events reported and the time between events, whether management initiatives intended to reduce entanglements have been effective (Pace et al. 2014). The annual number of events involving death or serious injuries related to fishing gear entanglements averaged 2.5 for right whales, 6.5 for humpbacks, 0.6 for fin whales, and 2.4 for minke whales. Annual entanglement rates increased during the study period, but evidence for increased rates of entanglement-related mortality was equivocal. No significant changes

occurred in waiting time (the number of days between entanglement events) in response to any of the management measures implemented to reduce large whale mortality between 1998 and 2009 (Pace et al. 2014). The authors concluded that the measures that had been introduced were generally ineffective in reducing whale deaths from entanglement. However they also noted that entanglement rates would need to have been reduced by around 50% or more in order to allow a change over a ten year time frame to be detected from reported carcasses or observed entanglements.

In most other areas there are insufficient data to detect changes in large whale entanglement rates in response to management measures. Hence there is a need to implement and evaluate measures based on estimates of expected risk reduction rather than observed incidents. An important aspect of evaluating risk reduction is assessing the compliance with any measures. Pace et al. (2014) did not have any data on rates of compliance and so could not distinguish between the effectiveness of mitigation measures in principle, compared to their implementation in practice.

Rates of non-fatal entanglements can provide an indication of rates of fatal entanglements but need to be interpreted with care. Management measures that reduce risk of any form of entanglement will not alter the ratio of lethal/non-lethal incidents, whereas measures designed to lessen the likelihood of mortality if an entanglement occurs, will alter this ratio (IWC 2015).

1.4 Mitigation strategies and stakeholder involvement

Although there has been awareness of fisheries bycatch problems for several decades (Reeves et al. 2013), few measures have emerged which both substantially reduce risk and are realistic to enforce over the long term. Methods for mitigating bycatch involve changing human behaviour, using technology, or changing animal behaviour to prevent interactions with gear (Dawson et al. 2013). Mitigation strategies include banning or restricting fishing in areas used by cetaceans, which is effective if properly enforced. If this is not possible then reducing fishing effort, or modifying gear to reduce risk of contact or entanglement are the main strategies known to reduce risk.

There are other strategies which are often part of take reduction plans for species, populations or fisheries. Whilst valuable for collecting and/or disseminating data and information, they cannot be considered as mitigation measures themselves. These include identifying research needs and conducting research (other than that which develops and evaluates mitigation measures), outreach strategies, and monitoring/observer schemes. These aspects are not considered in this report, which focusses on practical and technical measures aimed at reducing bycatch.

Successfully implementing any measures does however require extensive stakeholder collaboration and appropriate incentives or enforcement (Komoroske and Lewison 2015). Any management measures need to be implemented by the relevant fisheries management organisations. Hence FAO, Regional Fisheries Management Organisations and relevant authorities at a national level are critical. Piovano et al. (2012) noted that that 'socio-economic and emotional factors are essential for successful uptake of bycatch reduction technologies' and this is repeated in many other studies (see Lewison et al. (2011)). The necessary elements and different models for stakeholder collaboration are an essential component of any mitigation strategy, but are beyond the scope of this report since in most cases they are very case-specific. However, as one example, the 'Take Reduction Team' (TRT) approach in the US is generally considered an example of good practice, but requires a large commitment of resources and time, and objectives have not always been achieved. The teams

usually comprise scientists, engineers, fishers and managers, and meet regularly to review fisheries, whale distribution and entanglement data in order to advise the relevant fisheries managers about the most feasible and effective gear or fishing practice modifications which might then be mandated (McDonald and Rigling-Gallagher 2015, McDonald et al. 2016).

1.5 Categories of mitigation methods

For this review, mitigation measures were divided into two categories: measures to reduce the risk of contact with fishing gear, and measures to reduce risk of serious or fatal injury if entanglement does occur. Mitigation measures are reviewed through case studies where they have been implemented and evaluated.

Measures to reduce the risk of contact include general fisheries management that addresses over-capacity through reducing fishing effort, closed areas/fishing bans, acoustic alarms or 'pingers', gear modifications and alternative gear. Cetaceans can also become entangled in gear that is not being actively fished at the time. Minimising gear loss and wet storage of gear can reduce such risks.

In most cases, small cetaceans do not survive once they have become trapped in gear. However there are some gear types which are designed to enclose rather than entangle target species. Dolphins and porpoises which interact with this gear also become enclosed rather than entangled and so are often still able to come to the surface to breathe. There are ways in which animals can be released in these situations. For large whales modifying the strength of the gear can reduce the risk of entanglement allowing whales to break free.

2. MEASURES TO REDUCE RISK OF CONTACT

2.1 Reduce fishing effort

It can be assumed that if all other factors are equal, then for a specific type of gear the entanglement risk will be proportional to the amount of gear set. Hence total fishing effort is often a good indicator of entanglement risk and reducing fishing effort is an effective way to reduce risk. Benjamins et al. (2012) show a clear relationship between fishing effort off Newfoundland and Labrador and rates of humpback whale entanglement following dramatic changes in effort as a result of the collapse of the cod fishery.

Declining fisheries are often characterised by low profit, and by fishers having to work increasingly hard, setting more and more gear (Costello et al. 2016). These circumstances are likely to result in high bycatch rates as a proportion of landings (Myers et al. 2007). There has been widespread recognition for many years of the need to reduce overcapacity in global fisheries (e.g. Pauly et al. (2002)) but this has proven extremely challenging due to a combination of social and economic factors. Measures to regulate fishing effort have been used to control fishing-related mortality of target species in some situations in recent decades in management regimes such as the EU Common Fisheries Policy (Tidd 2013). However the considerable further potential to develop this approach will require a shift in attitudes within fisheries policy and management (Shepherd 2003).

Management regimes that regulate fishing mortality through quotas often have high levels of discards and bycatch (EU-Commission 2002), whereas management through effort limitation also reduces many environmental impacts including bycatch and entanglement. For example, Myers et al. (2007) suggested that reducing fishing effort in the Maine lobster fishery could both improve the economics and reduce entanglement risk to North Atlantic right whales. Compared to a similar

fishery in Canada, it was estimated that seasonal overlap of whales and fishing gear together with overfishing in the Maine lobster fishery, resulted in each lobster caught there posing a 100 times greater risk to right whales than in its Canadian equivalent.

In many areas there are conflicts within fisheries between fishing methods using static and mobile gear. Unfortunately, whilst mobile gear generally poses lower entanglement risks to large whales, it frequently has greater impacts on other aspects of the environment (particularly damage to the benthos from bottom trawls) compared to static gear with a higher entanglement risk. However, this is a broad generalisation and comparisons of relative risk and impact need to be evaluated on a case-by-case basis.

2.2 Closed areas/fishing bans

Area-based management has the potential to be effective if the area is in the right place, is large enough, effectively manages threats, if no new threats are added, and if the threats are not simply moved elsewhere to outside the protected area (Slooten 2013). Also key is that fisheries bans and restrictions must be timely. Fishing bans, and to a lesser extent, time-area closures can be unpopular with fisheries and onerous to enforce, although some no-take zones have been shown to be beneficial to fish stocks, which can potentially increase support amongst fishers. As bans are often only enforced when a species or population is *in extremis*, they can come too late to be effective (see, for example, vaquita and Māui dolphins below). It is rarely if ever possible to achieve 100% compliance with bans, and this, combined with the usually perilous state of the population once a ban has been put in place, often results in it being too late to arrest serious decline or prevent extinction.

2.2.1 High Seas and European Union (EU) Driftnet bans

In the 1980s and 1990s high levels of bycatch including cetaceans and other taxa in drift net fisheries became of increasing concern, leading to a United Nations General Assembly moratorium on the use of drift nets longer than 2.5km on the High Seas in 1992. Other nations and regions, the General Fisheries Commission for the Mediterranean (GFCM), and the International Commission for the Conservation of Atlantic Tuna (ICCAT) followed the UN Resolutions with their own similar legislation and regulations. The EU passed Council Regulation (EEC) No 345/92 also restricting net length to 2.5 km for drift nets used in EU waters and by EU vessels. This was followed in 2002 by a ban on all driftnets for the capture of Annex VIII species (such as marlin, swordfish and shark). In 2008, the use and carriage of all driftnets was banned in the Baltic Sea. Under ACCOBAMS (to which the EU is not a signatory, but individual member states are), signatory states have agreed on the prohibition of the carriage or use of any driftnets in the Convention Area, which covers the Black Sea, Mediterranean Sea and contiguous Atlantic area. Therefore EU vessels can carry and use small drift nets (less than 2.5km long) except in the Baltic, as long as they are not intended for capture of Annex VIII species; Annex VIII species caught in driftnets cannot be landed.

There have been considerable problems with the control and implementation of these regulations in the EU, in particular the 2.5km rule, where vessels have exploited loopholes in the legislation (Baulch et al. 2014). Although there have been clarifications and improvements, enforcement has not ceased to be a problem, given the intrinsic difficulties of regulating such fisheries which can operate covertly in remote places with a low risk of detection. For example, Baulch et al. (2014) report continued illegal driftnetting in Albania and Tunisia, with unconfirmed illegal activity in Italy, and Tudela et al. (2005) report the large-scale illegal swordfish driftnet fleet operating out of Morocco in the Alboran

Sea, resulting in bycatch, particularly of common dolphins (*Delphinus delphis*) and striped dolphins (*Stenella coeruleoalba*).

Although the UN high seas drift net ban has decreased mortality significantly in some species (Reeves et al. 2013), on the whole the bans can be more accurately described as a reduction in effort. However, as fisheries effort and bycatch data have been lacking, both before and after the bans, it is not clear how much the effort has been reduced, or if it has simply been moved elsewhere.

2.2.2 Harbor Porpoise Take Reduction Plan, Northeast US

The Harbor Porpoise Take Reduction Plan (HPTRP) in northeastern US was implemented in late 1998 following section 118(f) of the MMPA to reduce the level of serious injury and mortality of the Gulf of Maine/Bay of Fundy harbour porpoises (*Phocoena phocoena*) in Northeast sink gillnet and Mid-Atlantic gillnet fisheries (which target species such as Atlantic cod, haddock, pollock, flounder species, monkfish, and hake species), where the bycatch in 1990 was several thousand animals (Geijer and Read 2013). An element of the Plan included time-area closures. In the year prior to the HPTRP's commencement, estimated bycatch was 778 animals, which dropped to 323 in the first year of the Plan, to 79 in 2001, then rose to 1100 in 2005, levelling out to 792 in 2009, but still above the PBR¹ of 703 (Orphanides and Palka 2013)(also see *Pingers* Section (2.3)). Low compliance with regulations, including with respect to pingers, was the main factor contributing to this increase (Orphanides and Palka 2013). Fishing effort also shifted into areas not managed by the HPTRP, and a change in fisheries effort also occurred to target fish species such as monkfish which resulted in a relatively high porpoise bycatch. The plan was not flexible enough to accommodate these changes (Orphanides and Palka 2013). More fishing effort in previously low effort areas (such as Stellwagen Bank) could have been due to changes in the distribution of target species, or because the neighbouring area (Massachusetts Bay) was subject to both HPTRP seasonal closure and pinger requirements (Orphanides and Palka 2013). Furthermore, there was a strong correlation between cod landings and bycatch which suggests that, even in the early years of the Plan when the mitigation measures appeared to be working, the bycatch reduction might have been attributable more to reduced fishing effort than to Plan regulations (Geijer and Read 2013). NMFS amended the Plan in 2010 to address non-compliance and fisheries interactions occurring outside of existing management areas (NOAA-NMFS 2013). The 2010 amendments comprised spatial and temporal expansion of existing management areas, incorporation of new management areas, and the implementation of a consequence closure strategy, which closed specific areas to gillnet gear during certain times of the year if observed average bycatch rates exceeded specified target bycatch rates over the course of two consecutive management seasons (NOAA-NMFS 2013). However, there were disagreements over whether consequence closure target bycatch rates, which were based on the number of observed harbour porpoises caught per metric tons of fish landed between 1999 and 2007, accurately reflected the compliant bycatch rates given that fish landings had decreased. This led to the consequence closure strategy being removed from the plan in 2013 (NOAA-NMFS 2013).

2.2.3 Bottlenose Dolphin Take Reduction Plan, western North Atlantic

The Bottlenose Dolphin Take Reduction Plan (BDTRP), issued in 2006, aimed to reduce serious injury and death of bottlenose dolphin (*Tursiops truncatus*) inshore and coastal stocks in gillnets, and other coastal fisheries from New Jersey to the east coast of Florida. The Plan included restrictions on when gear of certain mesh sizes (small (≤ 5 inch), medium (≥ 5 inch to < 7 inch), large ≥ 7 inch)) could be set: during certain periods of the year, there were regulations on fishing at night which varied

¹ Potential Biological Removal (the procedure used within the US MMPA to assess the conservation implications of removals or takes). See Wade, P. R. (1998). Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. *Marine Mammal Science* 14(1): 1-37.

depending on area and mesh size (NOAA 2006). The average annual bycatch has been maintained at below PBR since the Plan was issued, and in that respect the Plan has been a success (McDonald et al. 2016).

2.2.4 False Killer Whale Take Reduction Plan, Hawaii

An element of the False Killer Whale Take Reduction Plan (FKWTRP), which aims to address false killer whale (*Pseudorca crassidens*) mortality in Hawaiian longline fisheries, is the establishment of two longline management areas. The FKWTRP pertains to the Main Hawaiian Islands Insular population and the Hawaii Pelagic stocks, the first of which is listed under the Endangered Species Act (NOAA 2012). False killer whales become hooked or entangled in Hawaiian longline fishing gear, both in the deep-set tuna fishery and the shallow-set swordfish fishery, often when false killer whales are depredating catch or bait on the lines. The False Killer Whale Take Reduction Team's Plan was issued in 2012 to address this threat. In the management areas, longline fishing around the Main Hawaiian Islands is prohibited year-round. There is a Southern Exclusion Zone south of the Main Hawaiian Islands which will close if the deep-set fishery reaches a specific level of observed bycatch. By mid-2015 there had been 16 observed false killer whale takes since the Plan's implementation, 15 of which were in the deep-set fishery (NMFS 2015). There had also been a shift in fishing effort to the northeast, with possible implications for the effectiveness of the Plan (NMFS 2015).

2.2.5 Dolphin Protection and Management Zones, Mekong (Irrawaddy dolphin)

In the Mekong, there has been a restriction on the use of gillnets to protect Irrawaddy dolphins (*Orcaella brevirostris*) in Cambodia (Ryan et al. 2011). Bycatch in gillnets is the principal cause of death for adult dolphins, and a Cambodian government order in 2006, followed by a sub-decree passed in 2012 created Dolphin Protection and Management Zones along 180km of the Mekong, where the use of gillnets with a mesh size of >4cm is banned. This legislation has been quite successful largely because of the high effort in implementation and removal of fishing gear, and has reduced, but not eliminated, bycatch in Cambodia (Ryan et al. 2011). In neighbouring Laos, community-based gillnet prohibition areas were ineffective (Ryan 2012), and the Irrawaddy dolphin was declared functionally extinct in Laos in 2016². In freshwater as well as marine environments, when populations span different countries without common legislative structures, implementing regulations is highly problematic.

2.2.6 Fishing restrictions, Gulf of California (vaquita)

In the Gulf of California, an intensively gillnetted area which is home to the endemic vaquita (*Phocoena sinus*), protected areas have thus far failed to arrest the species' collapse (Taylor et al. 2016). The demise of the vaquita is due almost-entirely to bycatch in gillnets (Rojas-Bracho and Reeves 2013). In the early 1990s, vaquita bycatch in gillnets was already known to be unsustainable (D'Agrosa et al. 2000). Unlike many other developing country bycatch issues, this has been relatively well-documented; the vaquita was listed by the IUCN as 'Vulnerable' in 1978, 'Endangered' in 1990 and 'Critically Endangered' in 1996. A zoned Biosphere Reserve was established in 1993, the International Committee for the Recovery of the Vaquita (CIRVA) in 1996, a Vaquita Refuge in 2005, followed by a Species Conservation Action Plan in 2008 (PACE-Vaquita), with an aim of eliminating gillnets, and therefore vaquita bycatch from both the Refuge and the vaquita's entire range by 2012 through buy-out (fishers changing livelihoods), switch-out (alternative gear) and rent-out (not fishing in the Refuge)(Rojas-Bracho and Reeves 2013). However, the challenges involved, chiefly with management, enforcement and multi-agency cooperation were considerable, and, whilst the measures were not without effect, the goal was not reached (Rojas-Bracho and Reeves 2013).

² http://www.panda.org/wwf_news/?282590/Irrawaddy-dolphins-functionally-extinct-in-Laos

Vaquitas declined from about 567 to 245 individuals between 1997 and 2008. Surveys in late 2015, after a two-year emergency gillnet fishing ban had been enacted (in May 2015), resulted in an estimate of 59 individuals, a decrease of 92% since 1997 (Taylor et al. 2016). A further analysis in November 2016 based on acoustic data suggested an average annual rate of decline between 2011 and 2016 of 39%, and that only approximately 30 vaquitas likely remained (CIRVA 2016). Although 'if deaths in gillnets were permanently eliminated, there is no reason to doubt that vaquita would recover' (Taylor et al. 2016), this prospect seems elusive, and the outlook is currently grim. The Mexican government has been unable to control a resurgence in the lucrative trade in the swim-bladders of totoaba, an illegally-fished croaker species, which is itself endangered, resulting in poor compliance with the emergency ban in spite of a well-resourced compensation scheme for fishers. Taylor et al. (2016) state that 'if the current, temporary gillnet ban is maintained and effectively enforced, vaquitas could recover to 2008 population levels by 2050', but it currently does not seem like it will be possible to verify this statement.

Rojas-Bracho and Reeves (2013) note that the vaquita has neither practical nor economic value, whilst the fishing industry has both. This was recognised in the late 1990s, when CIRVA recommended that, in addition to reducing bycatch to zero, the economic impacts of conservation measures should also be addressed through compensation, alternative livelihoods and development of alternative fishing gear (Rojas-Bracho and Reeves 2013). The emergency ban within the range of the vaquita in 2015 was also accompanied by a compensation scheme. However, to date this compensation has not been sufficient to discourage the continuing illegal totoaba trade. Rojas-Bracho and Reeves (2013) also note that in areas of the world where fishing is embedded in the culture of the area, especially artisanal coastal communities in developing countries, some people will just continue to fish no matter what, especially, but not exclusively, if bans are voluntary.

2.2.7 Area fishing restrictions, New Zealand (Hector's dolphin)

Hector's dolphins (*Cephalorhynchus hectori*) are endemic to New Zealand; populations have become fragmented, and have declined to an estimated 27% of 1970 levels due largely to fisheries mortality (Slooten 2013). Hector's dolphins are listed as Endangered by IUCN, whilst the North Island subspecies (Māui dolphin (*Cephalorhynchus hectori maui*)) is listed as Critically Endangered. Data collected on the east coast of South Island in the 1980s indicated the vulnerability of Hector's dolphins, and the high level of entanglement in gillnets, and led to the creation of the 1170km² Banks Peninsula Marine Mammal Sanctuary in 1988, restricting amateur gillnetting and prohibiting commercial gillnetting (Dawson and Slooten 1993), the area of which was extended in 2008. As the Sanctuary has been in existence for a comparatively long period of time, with a corresponding time series of mark-recapture data, it has provided the best opportunity to assess the efficacy of a closed fisheries area in cetacean conservation. Gormley et al. (2012) demonstrated a 90% probability that Hector's dolphin survival had improved between pre- and post-sanctuary periods, with mean survival rates estimated to have increased by 5.4%, and a 6% increase in mean annual population growth. However, these changes may not be adequate to protect the whole population because the Sanctuary is too small and regulations insufficient (Gormley et al. 2012, Slooten 2013).

The North Island population (Māui dolphin) was afforded some protection from gillnetting and trawling in 2003, and the size of the protected area has steadily increased to date, with over 6,200 square kilometres of coastal waters closed to set net fishing activity and 1,702 square kilometres to trawl fishing activity as of 2016 (Currey and Lundquist 2015). However, Currey and Lundquist (2015) estimated that the population was just 55 individuals over one year of age from surveys in 2011-12, whilst Baker et al. (2016) estimated 63 individuals of one year or over based on surveys from 2015-16. There is evidence of ongoing population decline and a level of human impact significantly

exceeding the level of PBR. The protected area for Māui dolphins was introduced too late and is also likely too small, and not strongly enough regulated, with gillnetting and trawling still continuing in certain areas (IWC 2016).

2.2.8 Gillnet restrictions, South America (*Franciscana*)

There are few estimates of bycatch for franciscana (*Pontoporia blainvillei*), which are subject to mainly small-scale coastal gillnet fisheries bycatch (Franciscana-Consortium 2016). In Argentina, there are systems of protected areas, some of which overlap with franciscana habitat, and have potential to incorporate gillnet bans in their development, although legal action taken to allow artisanal fishing in some provinces has precluded this (Franciscana-Consortium 2016). However, there is a summer gillnet ban in the province of Rio Negro, which was introduced in 2013, and there have also been efforts to place gillnets further offshore and use them as driftnets (Franciscana-Consortium 2016). In Uruguay and Brazil, there is also potential to develop protected areas for franciscana due to recent conservation legislation, and in southern and southeastern Brazil several restrictions on gillnet fishing including gillnet length, permitting, and time-area restrictions have been put in place. It is unclear, however, how effective any of these measures are in protecting franciscana, and how well they are being enforced (Franciscana-Consortium 2016). In 2015 the IWC established a Franciscana Task Team to further characterise fisheries and monitor bycatch (IWC 2016).

2.2.9 Time-area closures, US and Australia (large whales)

In situations where whales are only present in an area for a limited and predictable period each year then planned seasonal closures can be effective. For example, in New England, USA, NOAA introduced a seasonal closure for all trap/pot fisheries for the Massachusetts Restricted Area from January 1 to April 30 which is the main season for North Atlantic right whale (*Eubalaena glacialis*) presence.

Off the west coast of Australia there has been an upward trend in the number of humpback whale (*Megaptera novaeangliae*) entanglements reported between 1990 and 2010 in rock lobster fishing gear despite fishing effort declining over the same period of time. Much of the increase in entanglement incidents can be attributed to changes in regulation allowing the fishery to change from seasonal to year-round (Groom and Coughran 2012). IWC (2014) suggests that one solution would be for the fishery to return to being a seasonal one, avoiding gear in the water during whale migration. If this is not possible, another would be to only allow fishing in waters outside of the whales' migratory path if this can be determined.

2.3 Pingers/Acoustic alarms

Pingers are small battery-powered acoustic devices which are attached to gillnets and produce sounds (generally <150 dB re 1 μ Pa @ 1m, but some models are louder (up to 165 dB re 1 μ Pa @ 1m for the DDD-03 described by Kingston and Northridge (2011))) to deter small cetaceans from the vicinity of ensouffled nets, with the aim of reducing bycatch and also, in some cases, dolphin depredation (Dawson et al. 2013). When they work well, they can enable fishing activities to continue with the same or similar gear and regimes but with reduced bycatch, which can be preferable to having to change fishing gear or behaviour. Large reductions in bycatch of certain species have been achieved in controlled experiments with pingers. They appear to be particularly appropriate for use in developed countries with neophobic³ species (Dawson et al. 2013). Studies with harbour porpoise, franciscana, common dolphins, striped dolphins and beaked whales have

³ Behaviour defined by avoidance or retreat from an unfamiliar object or situation.

resulted in bycatch reduction (Kraus et al. 1997, Barlow and Cameron 2003, Palka et al. 2008, Bordino et al. 2013, Dawson et al. 2013).

However, pingers are not always effective for these species (see for example Berrow et al. (2008) where common dolphins failed to show an evasive response). Nor are they effective for all species, such as bottlenose dolphins, where results have been equivocal, with no strong evidence of a decrease in either depredation or bycatch (Dawson et al. 2013). Pingers used in the Pilbara trawl fishery of Western Australia were not effective in preventing bottlenose dolphins from entering the trawl (Stephenson et al. 2008, Allen et al. 2014). In the mid-Atlantic bottom trawl fishery, pinger use resulted in higher rates of bycatch of offshore bottlenose and Risso's dolphins (*Grampus griseus*), although pinger use, and records of pinger use were not systematic, and the sample size was small (Lyssikatos 2015). Pingers used in trials with Australian snubfin (*Orcaella heinsohni*) and humpback dolphins (*Sousa chinensis*) in coastal Queensland waters resulted in only slight behavioural responses, and were not thought to be an effective means of bycatch reduction (Soto et al. 2013). Amano et al. (2017) evaluated the long-term effectiveness of pingers with finless porpoise (*Neophocaena asiaorientalis*) in Omura Bay and found that, whilst pingers did induce avoidance of ensouffled nets, the effect only lasted a few months before the porpoises apparently habituated to the sounds.

In the case of harbour porpoises, Dawson et al. (2013) reviewed 14 controlled experiments using pingers in Europe and North America; on the whole they show substantial reductions in bycatch with no habituation. In the gillnet fishery in the northeast of the US, the reduction in bycatch under the US National Marine Fisheries Service Harbor Porpoise Take Reduction Plan (HPTRP) implemented in 1999 (which also included time-area restrictions, other gear modification requirements, outreach, training and education), resulted in 50-70% fewer porpoises bycaught in nets with pingers compared to nets without pingers between 1999 and 2007 (Palka et al. 2008, Orphanides and Palka 2013, Read 2013). Compliance and resulting bycatch varied, starting well, deteriorating and then improving somewhat (see *Closed Areas/Fishing Bans* section 2.2.2) (Palka et al. 2008, Orphanides and Palka 2013, Read 2013). In 2010 the HPTRP was modified (see *Closed Areas/Fishing Bans* section 2.2.2). The overall level of bycatch reduction was much lower than the 92% achieved in the original controlled pinger experiment in that area (Kraus et al. 1997), partly due to different mesh-sized gillnets being used, but mostly because of enforcement/compliance levels (Palka et al. 2008, Dawson et al. 2013, Orphanides and Palka 2013). There were also changes in the fisheries and environment over this time, with effort expanding into areas not covered by the HPTRP (Orphanides and Palka 2013)(see *Closed Areas/Fishing Bans* section 2.2.2).

An alerting device, described as a Porpoise Alarm (PAL) which generates sounds similar to harbour porpoise communication signals (Culik et al. 2015) has also been tested in German and Danish gillnet fisheries in the Baltic and North Sea. In trials during 2013/14 a significantly lower bycatch rate of harbour porpoise was observed in nets equipped with PAL devices in the western Baltic Sea, but there was no equivalent significant reduction in the bycatch rate in the North Sea (Culik et al. 2016).

In EU waters, where since 2004 EU Council Regulation 812/2004 requires pinger use by certain vessels over 12 m in length, the practical implementation of mitigation and compliance have also been impacted by pinger cost, reliability and failure rates (Kingston and Northridge 2011, Dawson et al. 2013, ICES 2016). The implementation of Regulation 812/2004 has been reviewed annually since 2009 by the ICES Working Group on Bycatch of Protected Species, based on reports from member nations. The UK has around 25 vessels required to use pingers and has had an active enforcement and monitoring programme in recent years (Northridge et al. 2015). Bycatch rates of harbour porpoises in UK fisheries up to 2014 have continued to be much lower in gillnets that are properly

equipped with pingers, suggesting no clear evidence of habituation. However, it is still unclear whether pingers are having any effect on the bycatch rates of dolphin species (Northridge et al. 2015). Those authors concluded that implementation of Regulation 812/2004 with a significant enforcement effort was expected to have reduced harbour porpoise bycatch in UK waters by around 15% from an estimated 1719 to 1468 individuals in 2014. Although pingers have been effective where they have been deployed, this only represents a small proportion of the total effort and so the overall effect on bycatch reduction has been limited.

The main gap in mitigation requirements of Regulation 812/2004 is that it only applies to vessels >12m length. Trials have been conducted using pingers on set nets set by smaller vessels in inshore fleets that are not covered by Regulation 812/2004 (e.g. Hardy et al. (2012)). Crosby et al. (2013) describe successful trials with a low cost pinger (Fishtek 'banana' pinger) that could be used by the inshore fleet.

The Pacific Offshore Cetacean Take Reduction Plan was issued in 1997 to address bycatch in the California/Oregon drift gillnet fishery which targets thresher shark and swordfish. Amongst other regulatory measures in the Plan, pinger use was mandated. Compliance with regulations in observed vessels has generally been high at >98%, considerably better than in the HPTRP in the Gulf of Maine, although an increasing number of vessels in the fleet are too small to have observers onboard (Carretta and Barlow 2011). Bycatch of common dolphins has approximately halved since pingers were introduced, and there has been no beaked whale bycatch, nor is there any apparent habituation (Carretta and Barlow 2011).

There has been relatively little use of acoustic alarms to try to reduce large whale bycatch compared to small cetaceans. When the IWC Scientific Committee discussed the use of pingers with respect to large whales in 2014 there was little recent information on experiments to test effectiveness of 'alarms' since Lien's work with simple alarms in Newfoundland in the 1980s (IWC, 2014 Annex J). Subsequently studies of commercially used devices on migration routes of humpback whales showed no measurable avoidance response (Harcourt et al. 2014, Pirota et al. 2016).

2.3.1 General limitations of pingers

Correct pinger deployment is important, including sufficient spatial coverage on nets, correct spacing, appropriate deployment depth and timely replacement of batteries (Palka et al. 2008, Kingston and Northridge 2011, Bjørge et al. 2013, Dawson et al. 2013, Larsen 2013). Nets with an incomplete set of pingers can have higher bycatch rates than those with no pingers at all, such as in the US Northeast gillnet fishery, where incompletely-covered nets had bycatch rates two to three times higher than nets without any pingers (Palka et al. 2008, Dawson et al. 2013).

Pingers can be very effective in certain fisheries, with certain species and a regulatory and compliance structure which also includes other mitigation methods such as time-area closures. However cost, reliability and compliance are key issues which limit their application. Mangel et al. (2013) trialed pingers in the small-scale Peruvian driftnet fleet, where common dolphins (*Dephinus* spp.), dusky dolphins (*Lagenorhynchus obscurus*), bottlenose dolphins, Burmeister's porpoises (*Phocoena spinipinnis*), and pilot whales (*Globicephala* spp.) are all bycaught. The pinger trial over 29 months resulted in a 37% reduction in bycatch, with the greatest decline for common dolphins (cf. Barlow and Cameron (2003)). Given that the current levels of bycatch in the fishery are >10,000 individuals annually (Mangel et al. 2013), this reduction constitutes a large decrease in mortality. However, the difficulties with using pingers, not least the cost in small-scale fisheries, remain a problem. Pingers have also been quite effective in trials with franciscanas; however, as in Peru, in the socio-economic environment in which the largely small-scale artisanal fisheries in which franciscana bycatch occurs, there are likely to be problems implementing pingers in a real-scale fishery; there are

also concerns about habituation and habitat exclusion (Bordino et al. 2013, Franciscana-Consortium 2016). Indeed, habitat exclusion and habituation are general concerns with pingers, in addition to other environmental, welfare and behavioural impacts such as the introduction of noise into the marine environment (Dawson et al. 2013, Larsen 2013).

2.4 Gear modifications/alternative gear

2.4.1 Light trawls to replace gillnets

Taylor et al. (2016) see the development and adoption of alternative gear and the marketing of the resulting seafood as a key path towards 'stopping the cascade of extinctions that will deplete coastal waters of local species'. Alternative gear developed in the Gulf of California to replace the gillnets which have caused the near-extinction of the vaquita comprises a light trawl which has been shown to be efficient at catching shrimp, and could replace gillnets in this fishery (Rojas-Bracho and Reeves 2013). However, the adoption of the alternative gear by fishers has not kept up with events. Continued illegal gillnetting for totoaba, in spite of a ban and compensation scheme (see 2.2.6) has led to a vaquita population crash.

2.4.2 Cod pots to replace gillnets

In the Baltic, the inshore cod fishery has trialled cod pots as an alternative to gillnets and longlines to lessen the catch losses and damage to fishing gear by grey seals (*Halichoerus grypus*) (Königson et al. 2015). Although catches in pots were affected by environmental and fisheries-related variables, pots still presented a useful alternative to standard fishing gear. Whilst this study was aimed at decreasing seal depredation rather than mitigating bycatch, it demonstrates that pots for finfish can viably replace gillnets in some fisheries, and are worth exploring as a means of bycatch mitigation in areas where large whale entanglement is not likely to be an issue.

2.4.3 Stiffened and acoustically reflective gillnets

Attempts have been made to alter the mechanical and acoustic properties of nylon gillnets. Gillnets made with 20% iron oxide in the twine polymer were tested in the North Sea. Although harbour porpoise bycatch was significantly lower in the iron oxide nets compared to controls, the target catch was also reduced to such an extent that they could not be considered a viable mitigation measure (Larsen et al. 2007). The authors concluded that it was the increased stiffness of the iron oxide nets which accounted for the reduction in catch rates for both cod and porpoises. Barium sulphate line was significantly stiffer than similar control nylon line and also more acoustically reflective (Mooney et al. 2007). However although some early studies had promising results (Trippel et al. 2003), this modification has not been demonstrated as effective at reducing cetacean bycatch without associated reduction in catch of target species. Acoustically reflective nets infused with barium sulphate and physically stiffened nylon gillnets have been trialled with franciscana in Argentina, but neither modification reduced bycatch (Bordino et al. 2013).

2.4.4 Exclusion grids on trawls

A semi-flexible exclusion grid composed of braided stainless wire and pipe has been used in the Pilbara Trawl fishery in Western Australia (Stephenson et al. 2008), where bottlenose dolphin bycatch was first documented in 2002 (Allen et al. 2014). The Bycatch Reduction Device (BRD) enables dolphins to swim out of the mouth of the net, or exit through a bottom-opening escape hatch. In 2008 the BRDs were moved forward in the net to provide a shorter escape route (Allen et al. 2014). Dolphins usually back down into the net towards the grid, detecting it by its pressure wave, then swim out of the net upstream. When BRDs were introduced, bycatch was reduced by about 45% from 18.8 to 10.3 dolphins/1000 trawls, although it is not known what condition the dolphins were in

on exit, or what their long-term survival rates were (Stephenson et al. 2008, Allen et al. 2014). BRDs were made compulsory in 2006, but after the initial reduction in bycatch, there was no further decline in bycatch rates. The Sea Mammal Research Unit at the University of St Andrews started working with the UK pelagic pair trawl fishery for sea bass in 2001, developing a selection grid/top-opening escape hatch system to mitigate common dolphin bycatch. As in the Pilbara Trawl fishery, a metal tubing grid seemed to assist dolphins with detecting how close they were to it by the pressure wave created by the grid (Stephenson et al. 2008). Trials in 2004-5 found that dolphins used the escape opening fitted into the net midway along its length, with 22% of dolphins exiting from the nets in this way (Northridge 2006). Those that did not escape appeared to have died well in front of the escape hatch and grid, implying that they did not find the escape hatch, and indicating that more escape hatches were needed in the nets to enable dolphins to find them (Northridge 2006).

2.4.5 Excluding devices on stownets

On the west coast of the Korean Peninsula, stownets are responsible for over 80% of the finless porpoise (*Neophocaena phocaenoides*) bycatch. Stownets, although fixed, work similarly to trawls with the strong tidal currents of the Yellow Sea acting like the pulling force in a trawl. It is possible to install an excluding device which prevents animals being drawn into the codend of the net. The fishery currently uses such excluders to keep out jellyfish in the summer months, and this also correlates with much lower finless porpoise bycatch. In 2016 the Cetacean Research Institute in the Republic of Korea, started trialing variations of the excluder device, to assess their efficacy for mitigating porpoise bycatch. If the trials are successful, the Ministry of Oceans and Fisheries may require the excluders to be used on stownets to prevent porpoise bycatch (IWC 2016).

2.4.6 Longline modifications

Entanglement in long-line fisheries is often associated with depredation, which has been reported in a number of odontocete species. In global reviews, Hamer et al. (2010) and Werner et al. (2015) report entanglement cases of baleen whales but assess that these probably occurred by coming into contact with the gear during natural foraging. For example, Pinheiro et al. (2013) describe entanglement of a baleen whale in longline gear off Brazil.

In the Chilean Patagonian toothfish demersal longline fishery, a physical depredation mitigation device known as a 'net sleeve' reduced catch depredation by sperm whales by over 80%. The lack of access to the catch was also believed to be responsible for the subsequent departure of the whales from the fishing grounds (Moreno et al. 2008). Longline devices have also been developed and tested in Australia and Fiji which deploy either metal chains or a hooped cage structure once the target species is hooked to protect it from depredation, and therefore also protect cetaceans from being bycaught (Hamer et al. 2015).

There are a number of methods that have been used to prevent depredation (Hamer et al. 2012), which result in fewer animals in the vicinity of the gear, or actually taking catch or bait. Werner et al. (2015) provide a comprehensive review of a range of techniques and rank them according to demonstrated effectiveness and potential promise as a mitigation measure. Of these, terminal gear modification (e.g. net sleeves or changes to hooks) was the only method that had been shown to be both effective and ranked 'high' for its promise as a mitigation measure. Increasing hauling speed, changing set length and moving away from areas with cetaceans have all been shown to be effective but were ranked 'medium' as mitigation measures.

In addition to the establishment of management areas (see above), the False Killer Whale Take Reduction Plan in Hawaii requires that only certain hook types can be used on longlines, to reduce

the number of false killer whales hooked, and reduce injury to any animals that are caught (NOAA 2012). A minimum diameter of monofilament branch lines is also required, which makes it more likely that a hooked animal will stay on the line, thus enabling vessel crew to release it properly, rather than it breaking the line and swimming away with gear still attached (NOAA 2012). In practice, it appears that hooks might be too strong, and branch lines too weak, leading to breakages in the line rather than at the hook (NMFS 2015). Studies to investigate the mechanics of depredation by false killer whales in Hawaii have indicated that the false killer whales take bait as well as target fish (Thode et al. 2016), so anti-depredation devices such as chains or cages which protect catch might not be an effective option in this case. Hook strength and shape has been shown to be an important factor in ensuring that non-target species can break free while not affecting target catch ((Bigelow 2012)

2.4.7 Gear modifications to creel/pot/trap fisheries to reduce risk of contact with large whales

The main modifications have involved reducing the amount of line in the water. IWC (2014) notes that one way to do this is by eliminating vertical buoy lines, using either grappling gear or remotely released buoy lines which are kept coiled on the trap until released for retrieval by the fisherman. Another option is to string traps together so that several traps require only one buoy line. However, if this technique is used, the line between the traps should have a very low profile in the water column using negatively buoyant 'sinking' ground-line which will lie along the sea bed. Lines linking creels/pots/traps are often designed to float to minimise abrasion on the bottom. These are often not taut resulting in floating loops that present a risk to any whale close to the sea bed.

Although technologies exist for underwater remote releases of buoy lines, these are still expensive and there are few workable systems in use in commercial fisheries. In addition, surface markers are currently used to indicate where gear has been set. New technologies such as smartphone apps showing gear locations could overcome this issue if used by all vessels in the fleet. Acoustic releases have been used for some years by individual fishers in the rock lobster fishery off New South Wales, Australia⁴. Mechanical devices to take the slack out of lines are relatively straightforward to make, but these can be complex to deploy and expensive. Thus there is no system that has been widely used as a way of tensioning lines to reduce entanglement risk.

2.4.7.1 REDUCING VERTICAL LINE

Reducing vertical line can be a compromise between reduced risk of contact and consequences of entanglement. For example, in New England, NOAA have introduced rules on minimum number of traps per trawl based on area fished and miles fished from shore to reduce the number of vertical lines in the water. In the SE US right whale calving grounds, NOAA require the use of single traps/pots (i.e., one trap/pot per buoy line) on the grounds that right whale calves would be more likely to survive an interaction with a single trap than with a trawl, which is made up of multiple traps per buoy line.

In Australia measures to reduce risks in the West Coast Rock Lobster fishery were introduced in 2015 during the season when humpback whales were most likely to be present (1 May to 14 November). These aim to minimise the amount of rope used on each vertical line. If less than 32.9m is used then there are no restrictions but for lines longer than 32.9m the top third of the pot line must be held vertically in the water column and the maximum length floating at the surface must not exceed 9.1 m. In addition, surface rope has been eliminated in waters deeper than 20m and there has been a reduction in float numbers to reduce possible entanglement points⁵. How et al. (2015) and How et al.

⁴ <http://www.southernrocklobster.com/lib/pdf/mf1838.pdf>

⁵ http://www.fish.wa.gov.au/Documents/rock_lobster/wrl_notice_board/whale_entanglement_letter_april_2015.pdf

(2016) evaluate the effectiveness of these regulations, concluding that a significant risk reduction seemed to have been achieved.

2.4.7.2 SINKING GROUND LINE

Sinking ground line was introduced in pot/trap fisheries in a number of areas off the east coast of the US in 2009 (NOAA 2008). These measures have received some criticism from the fishing industry because of the increased abrasion to lines particularly on rocky bottoms. Johnson et al. (2005) identified ground line as posing a high potential risk of entanglement, but the risk reduction associated with sinking ground line has not been quantified.

2.5 Reducing gear loss

Lost gear as part of 'marine debris' may continue to pose an entanglement risk and in some cases this risk may be as severe as when the gear is actively fished, but there are few data to help evaluate this.

Concerns have been raised that measures to reduce vertical lines may increase the rate of lost gear. For example if there are two end-lines on a string of traps then they may still be recovered without grappling if one end-line is lost. Lower breaking strain line and weak links have also been implicated in the loss of end-lines used to recover gear. Having more traps joined together can also make gear more difficult to recover and raise safety concerns. NOAA (2015) exclude certain areas from requirements for multiple traps per surface marker because of such safety concerns.

However, even unmodified gear is subject to loss across fishing fleets. Such losses have proven difficult to quantify but are related to severe weather, interactions with shipping and mobile fishing gear (e.g. trawls). In some areas unpredicted advances in sea ice can result in large scale gear loss (Citta et al. 2013). The economic implications of gear loss compared to the value of catches vary between fisheries and result in some fisheries being prepared to accept a high risk of gear loss. Areas with high risk of gear loss such as shipping lanes are often the most dangerous to work but some fishers feel forced to take such risks. Fisheries managers could consider licensing systems for gear which reduce incentives to risk gear loss or closing areas where there is a particularly high risk of gear loss.

Fisheries management regimes can have a substantial impact on the risks of gear becoming lost. For example, prior to 2006, crab fisheries in Alaska were managed as a 'derby' system where boats were only allowed to fish for very short, predetermined periods. This resulted in gear often being set in very poor weather with resultant high loss rates. With the introduction of individual fishing quotas allowing skippers more flexibility to choose when to fish the annual loss rate dropped from an estimated 10-20% of pots fished annually to 1-4% (Citta et al. 2013). Although the Bering Sea-Aleutian Island Crab Rationalization Program was introduced with an aim to improve the fishery, a further benefit of reduced fishing effort and reduced gear loss is likely to be a substantial reduction in entanglement risk (Citta et al. 2013).

2.6 Addressing issues of wet storage/setting gear to preserve use of an area

There is anecdotal evidence from many fishing communities of leaving static gear in the water when it is not being actively fished (for example creel pots which are not baited), but where it nevertheless presents an entanglement risk. It is particularly difficult to quantify the extent to which this occurs and the reasons for leaving gear in the water are often location-specific.

A better understanding of why gear is being left in the water when not fishing would help address the issue. The provision of communal storage facilities ashore may reduce 'wet storage' of gear which will be at some risk of being lost if left at sea and also increased fouling. Restrictions on the

gear allowed per vessel may also help to ensure that all static gear is regularly checked and removed when not in use.

If fishers are leaving gear in place/*in situ* to preserve their patch rather than to actively fish, then this will be wasting time and fuel which ultimately has an economic as well as an environmental cost. Better co-ordination between fishing vessels could reduce this considerably to the benefit of the industry and reduced entanglement risk. For example, a smart phone app. used across the fleet which allowed boats to set 'virtual gear' would be a possible solution. This would require consensus across all those fishing in an area together with careful consideration of a set of rules but could increase profitability for all involved. Such methods may also be needed to avoid gear conflicts if systems without surface marker buoys are developed.

In areas used for calving by North Atlantic right whales in federal waters of the southeast US, it is now a requirement for trap/pot gear to be brought back to shore at the end of each trip. The aim is to ensure that gear is not left unattended for long periods of time so that there can be a more rapid response to any entanglements⁶. In the Australian West Coast Rock Lobster fishery, pots must be hauled every seven days.

3. MEASURES TO REDUCE RISK OF SERIOUS OR FATAL INJURY IF ENTANGLEMENT DOES OCCUR

3.1 Release programmes/training

Release programs, and the necessary training to make these possible, operate in some areas. In general, animals caught in gillnets do not survive, as they cannot reach the surface, and so die, although occasionally release is possible if nets are very close to the coast (Scheidat 2016).

3.1.1 Pound nets (harbour porpoise)

In Denmark porpoises which have become trapped in pound nets can be released. Pound nets ('Bundgarn') are used in all Danish waters apart from the North Sea and comprise a lead net extending from the beach for 1km, ending in a trap in the shape of a bag. If porpoises become trapped, they can breathe at the surface, make shallow dives, and do not become entangled. They are therefore rarely injured, and are in good condition when released (Scheidat 2016).

3.1.2 Herring weirs (harbour porpoise)

In the Bay of Fundy herring weir fishery, which targets juvenile herring, harbour porpoises can also be released if they become trapped (Harbour Porpoise Release Program). Herring weirs are large stationary traps placed in shallow water close to the shore which catch herring moving into deeper water. If harbour porpoises are following schools of herring, they can become trapped, but, like in the Danish pound nets, they can swim, feed, and breathe. The release program was developed in 1991 and assists fishers who find porpoises in their weirs to release them using a 'mammal seine', divers and a release skiff (Scheidat 2016). Since 1991, over 700 harbour porpoises have been released from around Grand Manan Island, with a success rate of about 94%. The number of porpoises reported as trapped in weirs has varied from 6 in 1996 to 312 in 2001⁷.

3.1.3 Tuna gillnets (dolphin species)

There is a WWF-led programme of release in Pakistan where dolphins (bottlenose (*Tursiops aduncus* and *Tursiops truncatus*)) and spinner dolphins (*Stenella longirostris*) are caught in tuna gillnets, although in practice the dolphins do not survive (Shahid et al. 2016).

⁶ http://www.greateratlantic.fisheries.noaa.gov/stories/2014/25_new_whale_protection_measures.html

⁷ <http://www.gmwsrs.info/>

3.1.4 Longlines (*false killer whales*)

In addition to the establishment of management areas and gear modifications, the False Killer Whale Take Reduction Plan includes improved training for vessel owners and captains on avoiding interactions with false killer whales, and on handling and release of hooked animals, as well as better information onboard vessels about marine mammal handling, informing the captain of entanglements, and supervision of handling by the captain (NOAA 2012). In practice, captains have not always been present at all interactions, and some crew handling might have been inadequate leading to higher-than-expected serious injuries and 12 interactions where the line broke or was cut (NMFS 2015).

3.1.5 Purse seines (*dolphin species*)

The tuna-dolphin fishery in the Eastern Tropic Pacific (ETP) also involves a release programme, although it is in a class of its own in mitigation terms. In many fisheries, bycatch is unwelcome, and there is a general will to mitigate it (Read 2013). There are also fisheries where cetaceans may not be specifically targeted, but their capture is not unwelcome, as they have market value as bushmeat or bait (Young and Iudicello 2007, Reeves et al. 2013, de Boer et al. 2016, Van Waerebeek et al. 2016). There are also fisheries where dolphins are deliberately targeted (e.g. Mangel et al. (2013)). However in the case of the purse-seine fishery for tuna in the ETP, dolphins are directly targeted, but then released. Because of the association between tuna and dolphins in the ETP (Scott et al. 2012), the purse-seine fishery which developed from the 1960s and into the 1970s used dolphins to find tuna, chasing and encircling both tuna and dolphins together in their nets. The main dolphin species killed were pantropical spotted dolphins (*Stenella attenuata*), spinner dolphins and common dolphins; from 1960 to 1972, more than 4 million dolphins were killed by yellowfin tuna fleets in the ETP, significantly depleting several populations (Wade et al. 2007). The level of mortality became clear, and the US Marine Mammal Protection Act, passed in 1972, included provisions for reducing dolphin bycatch through improved fishing methods. Measures such as scientific studies, increased regulations, observers on fishing vessels and gear inspections were required to ensure dolphins were released from nets, and bycatch was eventually reduced by two orders of magnitude (Gerrodette and Forcada 2005). The tuna-dolphin issue is complex and as noted, because the fishery is unusual in targeting dolphins without the intent to kill or otherwise remove them, the mitigation methods used are not readily transferrable to other situations. However, it is noteworthy that, in spite of some thirty years of management actions by US and others, and a dramatic reduction in bycatch (99% reduction in the international fleet, whilst the US fleet no longer sets on dolphins), northeastern offshore spotted dolphin and eastern spinner dolphin populations have not shown clear signs of recovery (Gerrodette and Forcada 2005). This may be due to underreporting of bycatch, and effects of chase and encirclement on dolphin survival and reproduction, so-called 'cryptic' bycatch (Gerrodette and Forcada 2005, Reeves et al. 2013). It may also be that expectations of rapid dolphin population recovery are not realistic; the removal of large biomasses of both tuna and dolphins from the ETP may have long-term ecosystem impacts that go beyond observed mortality and retard or prevent full population recovery (Gerrodette and Forcada 2005, Wade et al. 2007, Gerrodette et al. 2012).

3.1.6 Large whale disentanglement

The IWC has held a number of workshops and training sessions for large whale disentanglement. An important motivation for this work has been welfare considerations (IWC 2010, IWC 2012). It has been clearly recognised that disentanglement is not itself a prevention measure and only a small fraction of the entanglements that occur are likely to be successfully disentangled. For example, even in the Gulf of Maine off the US east coast with highly developed reporting systems, the likelihood

that an entangled whale is reported is only around 10-15% (IWC 2016). However, in addition to the clear welfare benefits to the whales themselves, disentanglement provides an opportunity to gather information which can assist in developing prevention measures (Mattila et al. 2007), and one objective of IWC disentanglement initiatives is to gather data that leads to prevention.

In South Africa many large whale entanglements have been related to nets set parallel to the shore to protect bathers from sharks. Between 1981 and 2009, interventions were successful in removing gear from 81% of whales entangled in such shark nets off KwaZulu-Natal (38 humpback whales, 17 Southern right whales (*Eubalaena australis*)), while 11 humpback whales and 2 Southern right whales were found dead (Meyer et al. 2012). The rate of successful disentanglement for these shark nets was considerably higher than is generally the case for other fishing gear.

3.2 Weak links and line strength

Large whales are able to exert considerable force on gear and may be able to break free if gear is suitably modified. Weak links on all flotation devices and/or weighted devices attached to the buoy line (except traps/pots, anchors, and leadline woven into the buoy line) were introduced in some east coast US fisheries from 2008 (NOAA 2008). These links have a maximum breaking strain of 2.7 kN. New measures (NOAA 2015) for Florida state waters (North Atlantic right whale calving grounds) have a maximum weak link of 0.9 kN. The weak link must be designed so that the bitter end of the buoy line is clean and free of knots when the weak link breaks plus each weak link must be installed as close to the buoy, flotation and/or weighted device as possible. Gear that is splice-free, knot-free, and/or free of attachments is believed to be more likely to slide through the whale's baleen rather than becoming lodged in the mouth or elsewhere.

Knowlton et al. (2016) suggested that reduced breaking strength line could reduce entanglement risk for large whales. Their results suggested that broad adoption of ropes with breaking strengths of ≤ 7.56 kN could reduce the number of life-threatening entanglements by at least 72%, and yet could provide sufficient strength to withstand the routine forces involved in many fishing operations.

The maximum breaking strength of vertical line in southeast US waters (Southeast Restricted Area North) has also been set at 9.8 kN (6.7 kN in Florida state waters). Elsewhere, where no measures have been taken to reduce line strength, most vertical lines are considerably stronger than this. This is partly due to large numbers of traps being set together and also is affected by weather and swell conditions. For example, in Alaska crab fisheries, buoy lines commonly have breaking strengths in excess of 30 kN and buoy eyelets commonly have breaking strengths greater than 4.4 kN. This strength of gear may allow it to be carried away by ice while still presenting a vertical line hazard (Citta et al. 2013).

4. DISCUSSION

Mitigation of cetacean bycatch and entanglement has proved a challenging and intractable problem for decades (Reeves et al. 2013). As shown by the case studies reviewed here, there are rather few examples where successful mitigation strategies have been effectively implemented. Where cetacean bycatch has declined it has most often been because of changes to the fishery resulting in a reduction in effort using gear that poses a high risk to cetaceans. Such changes have been motivated by economic factors or catch regulations, rather than reflecting a strategy to mitigate cetacean bycatch.

Whilst fisheries bans and time-area closures should be the most fail-safe means of mitigation by ensuring there is no overlap between fisheries and cetacean populations, enforcement and compliance, especially in the long-term in artisanal fisheries in developing countries, is difficult.

Similarly, using technology which is expensive and requires maintenance, such as pingers, is not viable in many of the world's fisheries. In some cases (as shown by the vaquita and Hector's dolphin case studies), closures have only been implemented after the cetacean population has already been severely depleted. Responding to evidence of bycatch or entanglement as soon as it becomes apparent is likely to be much more effective, and less onerous to the fishery in the long-term, than if action is not taken until there is an obvious conservation problem. Even where there are insufficient data to demonstrate that bycatch may be unsustainable, for example by using reference points such as PBR, there are nevertheless strong welfare arguments to address bycatch. For example, cases of entanglement of North Atlantic right whales have been described as 'one of the grossest abuses of wild animal sensibility in the modern world' (Moore et al. 2006). In the US, the MMPA sets a zero mortality rate goal for fisheries interactions, and within Europe ASCOBANS maintains the goal of reducing bycatch of small cetaceans towards zero. These objectives provide a clear mandate to address any apparent bycatch mortality.

The most promising solutions are fisheries-based and lie with the development of alternative gear to replace current fishing methods such as gillnets. As with the problems of seal depredation on finfish aquaculture, it is preferable to make gear interactions impossible, rather than using deterrents to attempt to prevent them. Some of the alternative gear/modifications discussed have promise especially if, as Taylor et al. (2016) point to, there are corresponding efforts to promote seafood that has not been caught in fisheries with cetacean bycatch.

Bycatch reduction techniques for other megafauna (seabirds, and marine turtles) involving practical and effective gear modifications have been developed in some situations (e.g. circle hooks for turtles and albatross streamers). No such simple solutions have been found for modifying gear in a way that reduces cetacean bycatch. Indeed, Senko et al. (2013) evaluated case studies involving bycatch of sea turtles, albatross and the vaquita and found that gear modifications were the most widely used and generally most promising technique compared to time-area closures, bycatch limits or buy-outs. However, the proposed modification for fisheries affecting the vaquita was essentially to switch from gillnets to light trawls and so could more realistically be called alternative gear. Where modifications have been effective for cetaceans these have sometimes resulted in reduced catches, or involved relatively expensive electrical equipment such as pingers, or remote releases to avoid vertical line. The expense of such systems effectively rules them out for many situations. However, the trials in the Republic of Korea of an excluder device for finless porpoises may prove an exception where a small mechanical modification can be effective.

Progress continues to be made on potential new mitigation methods with a number of trials in several areas. In East Africa, low-cost acoustic plastic bottle reflectors and mechanical glass bottle alarms are being trialled in driftnet fisheries (P. Berggren, pers. comm.). In German fisheries in the Baltic Sea automatic longlines and jigging machines have been investigated as alternative to gillnets (Detloff 2015).

This review has focussed on what are often described as 'command and control measures', including effort reduction, time/area closures, gear modifications and restrictions. However, whilst previous studies may help inform new approaches, past experiences will rarely provide an off-the-shelf solution. Furthermore, addressing cetacean bycatch must be integral to fisheries management strategies. The most generally effective mitigation of cetacean bycatch and entanglement is reduction in effort, starting with those fisheries that have the largest bycatch. Proposed high-level strategies to improve fisheries management and address bycatch vary from better integration of traditional approaches (e.g. (Lewison et al. 2011)) to incentive based approaches motivated by economics (Lent and Squires 2017).

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