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Report of the

EXPERT WORKSHOP ON MEANS AND METHODS FOR REDUCING MARINE MAMMAL MORTALITY IN FISHING AND AQUACULTURE OPERATIONS

Rome, 20−23 March 2018

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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PREPARATION OF THIS DOCUMENT

This is the report of the Expert Workshop on Means and Methods for Reducing Marine Mammal Mortality in Fishing and Aquaculture Operations, held in Rome from 20 to 23 March 2018. The materials in Appendix 3 (including 3A and 3B) are reproduced as submitted and have not been reviewed by the workshop participants and have not been edited by FAO.

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ABSTRACT

One of the greatest threats to species and population survival of marine mammals with their relatively slow growth and low fecundity comes from inadvertent interaction with, or capture in, fishing and aquaculture operations. FAO members have expressed great concern about bycatch of marine mammals at recent sessions of the Committee on Fisheries (COFI). At its Thirty-First Session in 2014 the Committee reiterated its support for FAO's ongoing work on bycatch management and reduction of discards, and requested FAO to expand its efforts to effectively implement the International Guidelines on Bycatch Management and Reduction of Discards, addressing all fishing gears where bycatch, including, *inter alia*, that of marine mammals, and discards were a problem. At its Thirty-Second Session in 2016, the committee welcomed the offer of the United States of America to fund an expert workshop to review the findings of recent international marine mammal bycatch workshops. Within this context, FAO convened the Expert Workshop on Means and Methods for Reducing Marine Mammal Mortality in Fishing and Aquaculture Operations in Rome, Italy from 20 to 23 March 2018, which was attended by twenty-seven experts in marine mammal science and bycatch mitigation. The workshop reviewed the current state of knowledge on the issue of marine mammal bycatch, and evaluated the efficacy of different strategies and measures for mitigating bycatch and their implementation. The workshop produced some key technical outputs, including an extensive review of techniques across different gear types and species, together with a summary table and a draft decision-making tool (decision tree) which could be used to support management decision-making processes. The workshop recommended that FAO develop Technical Guidelines on means and methods for prevention and reduction of marine mammal bycatch and mortality in fishing and aquaculture operations in support of FAO's Code of Conduct for Responsible Fisheries and as a supplement to International Guidelines on Bycatch Management and Reduction of Discards. The workshop also recommended that FAO consider establishing a global capacity development programme to support developing States in the application of the proposed guidelines.

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OPENING OF THE MEETING AND WELCOMING REMARKS

1. FAO members have expressed concern about bycatch of marine mammals at recent sessions of the FAO's Committee on Fisheries (COFI). At its Thirty-First Session (COFI31) in 2014 the Committee reiterated its support for FAO's ongoing work on bycatch management and reduction of discards and requested FAO to expand its efforts to effectively implement the International Guidelines on Bycatch Management and Reduction of Discards, addressing all fishing gears where bycatch, including, *inter alia*, that of marine mammals, and discards were a problem.

2. In 2016, at its Thirty-Second Session (COFI32), the Committee welcomed the offer of the United States of America to fund an expert workshop to review the findings of recent international marine mammal bycatch workshops.

3. Within this context, FAO convened an Expert Workshop to consider means and methods for reducing marine mammal mortality in fishing and aquaculture operations. The agenda of the workshop is attached as Appendix 1.

4. FAO technical officers, FAO consultants and experts with relevant expertise from governments, inter-governmental organisations, non-governmental organisations and academic institutions attended the workshop. Participants included marine mammal biologists, fishing gear technologists, policy specialists and conservation scientists. The participant list is provided in Appendix 2.

5. Mr Ari Gudmundsson, Head of FAO's Fishing Operations and Technology Branch, opened the meeting, welcoming participants.

6. Mr Matthew Camilleri, Senior Fisheries Officer of FAO's Fishing Operations and Technology Branch, further elaborated on the objectives and context of the workshop. Mr Camilleri explained that incidental capture of marine animals, including marine mammals, is covered under the FAO's Code of Conduct for Responsible Fisheries and in the International Guidelines for Bycatch Management and Reduction of Discards. These guidelines provide overarching guidance on the issue but do not provide advice regarding preventing or reducing mammal bycatch specifically.

7. Mr Camilleri also provided further information about FAO's International Plans of Action (IPOAs) on seabirds and sharks that are taxa-specific supporting instruments under the International Guidelines. Mr. Camilleri went on to explain the differences between the instruments under the Code of Conduct and what options might be available for FAO on the issue of marine mammal bycatch.

8. Ms Nina Young of the National Oceanic and Atmospheric Administration (NOAA), the United States of America, welcomed participants, and briefly outlined the work carried out by NOAA on global marine mammal bycatch since 2007.

9. Introductions around the table took place.

10. Mr Simon Northridge was selected as the workshop facilitator.

NEW RESEARCH AND REGIONALLY SPECIFIC CASE STUDIES

11. Workshop participants were provided with a background document prepared by the New England Aquarium before the meeting. The document summarised current knowledge on means and methods for reducing marine mammal mortality in fishing and aquaculture operations, drawing from previous workshops on marine mammal bycatch (Appendix 3).

12. Selected participants were invited to present on a range of techniques and strategies to reduce marine mammal bycatch.

13. Discussions following presentations and during breakout group and plenary discussions highlighted the following themes:

    a) the importance of quantifying reference levels of marine mammal populations that subject to bycatch that would allow the population to be sustained or to recover, whilst acknowledging a lack of data particularly for small-scale fisheries and those in developing countries;

    b) the social, economic and political challenges associated with the implementation of marine mammal bycatch mitigation measures;

    c) the impact of illegal, unreported and unregulated (IUU) fishing;

    d) the difficulties of identifying the origin of fishing gear and the individual components involved in marine mammal bycatch in the absence of sufficient gear-marking and the role that the recently passed FAO Voluntary Guidelines on the Marking of Fishing Gear might play;

    e) the importance of focusing on preventative measures, including gear switching, if applicable, as opposed to reducing the severity or lethality of bycatch once it has occurred;

    f) the difficulty of implementing effective marine mammal bycatch mitigation when overarching fisheries management and enforcement are limited or absent;

    g) the importance of an ecosystem-based approach to fisheries management when considering the impacts of bycatch and options for marine mammal bycatch mitigation;

    h) the potential role of seafood certification schemes in the uptake and implementation of marine mammal bycatch mitigation measures;

    i) the importance of identifying socioeconomic and other incentives for adopting alternative techniques, practices, or gears by fishers;

    j) the importance of recognising the challenges which may be faced by small-scale fisheries and developing States in implementing and enforcing effective bycatch mitigation measures and technologies and addressing this through capacity development; and

    k) the potential for bycatch mitigation technologies using simple, cost-effective alternatives made of readily available materials where cost or accessibility is likely a barrier to implementation;

IDENTIFYING AND COMPARING AVAILABLE MARINE MAMMAL BYCATCH REDUCTION TECHNIQUES

13. The participants split into two breakout groups to work on a table summarizing available marine mammal bycatch reduction techniques, examining gear types, modifications, and techniques that had been tested for various marine mammal species and to what extent these techniques had been proven effective or require further testing. The table that was further developed immediately after the workshop is included in Appendix 4.

14. It was noted that it would be useful to include the costs of different techniques in the summary table; however, since many factors influence costs, it was agreed that this should not be included at this time.

15. Workshop participants were introduced to a draft decision-making tool that may help managers evaluate management decisions when faced with marine mammal bycatch problems in their fisheries. The draft decision tool, which was extensively developed and discussed at the workshop, and further improved immediately after the workshop, is included in Appendix 5.

16. Workshop participants discussed acoustic deterrents and spatial management techniques in detail, recognizing that these two strategies have been the focus of widespread use and evaluation.

17. Gear switching was also discussed as a potentially effective measure within specific contexts.

18. Some mitigation practices rely on releasing animals that have been caught or entangled, such as providing mechanisms for animals to escape from a trawl or a trap. For these techniques, there is a need for increased research on the extent to which post-capture and post-release survival influences overall mortality rates of marine mammals.

Acoustic deterrents

19. 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.

20. Workshop participants expressed concern that the use of acoustic deterrents without appropriate management oversight of their implementation may not effectively address the bycatch problem and can result in potentially negative consequences to fishers, marine mammals and the environment in which they are deployed, including habitat exclusion, noise pollution, and safety concerns. Improper or unmanaged uses of acoustic deterrents may lead to assumption that the marine mammal bycatch problem has been solved, but in fact it may not.

21. Environmental Impact Assessments (EIAs) were mentioned as a way of assessing risks associated with acoustic deterrents. Specific reference was made to existing tools such as the Convention on Migratory Species (CMS) Guidelines on Environmental Impact Assessments for Marine-Noise Generating Activities which include specific guidance related to the use of pingers.

Time-area closures

22. The workshop discussed time-area closures as an approach to preventing marine mammal bycatch. The workshop considered such measures as being those that range from fully protected areas with no fishing to seasonal or dynamic area closures with fishing gear restrictions.

23. Like pingers and other methods of reducing bycatch, the design of time-area closures requires good baseline data on marine mammal habitat use, fishing effort, and other variables. When formulating networks of these areas, it is important to engage fishers and other key stakeholders throughout the process from initiation to implementation.

24. Different fisheries pose varying entanglement and bycatch risk to marine mammals in different parts of their range. Collaboration between jurisdictions can enhance the effectiveness of time-area closures across the total range of a population. Instruments such as regional fishery management and intergovernmental agreements and conventions may support multi-States efforts.

25. Time-area closures need to be of appropriate size, in the right locations, implemented during appropriate times, and effectively managed to mitigate the bycatch threat, and to avoid introducing new threats.

26. Selecting the locations of time-area closures needs to avoid the risk of redirecting fishing effort to other areas in which the potential risk of bycatch is even greater.

27. For all of the bycatch mitigation methods discussed at the workshop, it is critical to decide where and when the method will be used. In practice, most fisheries that use pingers also use area-based protection measures.

CONCLUSIONS

Impacts of marine mammal bycatch

28. Workshop participants noted that among approximately twenty marine species known to have become extinct in the past 400 years, an unusually high proportion has been marine mammals. Steller's sea cow, Caribbean monk seal, and Japanese sea lion are all now extinct. At least four marine mammal taxa are in imminent danger of becoming extinct. Yangtze River dolphin (baiji) has not been sighted since 2006 and is likely extinct, while there are fewer than 30 vaquita porpoises, 100 Māui dolphins (a subspecies of Hector's dolphin), and 450 North Atlantic right whales. Several other subspecies or populations are similarly critically endangered. Marine mammals, with slow population growth rates and many with low population sizes, are vulnerable to extinction. Overall, marine mammal bycatch is the greatest global threat facing marine mammals and often one of the key drivers for animals facing extinction.

29. Workshop participants emphasized that for some species, subspecies, and populations of marine mammals, often endemic to limited areas and occurring in very small and declining numbers, immediate action is needed to stop their bycatch-driven declines. Workshop participants agreed that for critically endangered marine mammals, the only viable option for preventing extinction is to eliminate all fishing-related mortality. If this does not happen, more human-caused marine mammal extinctions are inevitable.

30. Workshop participants also noted that there is an overwhelming bycatch risk to marine mammals, in general, posed by gillnets (*e.g.*, drift, set, and other entangling nets) that is disproportionate to the risks from other gear types (Appendix 3). Significant data gaps remain including marine mammal bycatch levels and population estimates to assess impacts. Participants also noted that IUU fishing could, in some cases, be a significant cause of or exacerbate marine mammal bycatch (*e.g.*, vaquita).

31. Workshop participants further noted that, even when non-lethal, prolonged entanglement in fishing gear negatively affects the health and welfare of individual animals and can also lead to population-level effects including reduced fecundity and survival.

Mitigation measures

32. Workshop participants agreed that marine mammal bycatch mitigation strategies encompass both the prevention and reduction of incidence and severity, and agreed that the first priority of any bycatch management strategy should be the prevention of entanglement or bycatch. Workshop participants noted the range of currently available marine mammal bycatch mitigation techniques, many of which are in use (Appendix 3).

33. Workshop participants further noted that fishery managers must set clear conservation and management objectives and bycatch reduction targets, in accordance with the FAO Code of Conduct for Responsible Fisheries, the UN Straddling Stocks Agreement and other intergovernmental and regional fishery management organization agreements governing or implementing conservation and management measures related to fisheries and marine mammals.

34. Workshop participants also noted the importance of engaging and incentivizing the fishing community and developing partnerships among all stakeholders to develop and test marine mammal bycatch mitigation measures.

35. Workshop participants noted the importance of evaluating whether marine mammal mitigation measures are meeting the identified conservation and management objectives set for species and populations. They further noted the importance of monitoring affected populations and, where appropriate, monitoring post-capture health (including reproductive success) and survival of individuals.

36. Workshop participants also noted that fishery managers should select the most effective and not necessarily the most convenient mitigation measures for achieving conservation objectives and targets.

37. Workshop participants agreed that some mitigation measures have been extensively tested and are being used in bycatch reduction programs. Workshop participants agreed that other mitigation measures are at a more experimental phase and require further testing and refinement. Workshop participants noted that bycatch reduction results may vary between experimental and operational conditions.

38. The workshop participants agreed that the table summarizing marine mammal bycatch reduction techniques across different gear types and species groups (Appendix 4) represents the current state of knowledge on approaches to marine mammal bycatch reduction. Workshop participants agreed that a table of this kind requires periodic updating to maximize its usefulness.

39. While the expert workshop focused on spatial management, gear modifications and gear switching, workshop participants acknowledged that improved fisheries management (e.g., reduction in fishing effort) can contribute to bycatch reduction.

40. Workshop participants acknowledged that a tool such as a decision tree is useful to expedite the identification and implementation of effective bycatch mitigation measures. Workshop participants agreed a decision tree can guide decision-makers in identifying assessment needs, possible management or mitigation measures, and adaptive management strategies through ongoing bycatch and population monitoring and evaluation. Workshop participants produced a draft decision tree that would benefit from further elaboration and refinement (Appendix 5).

Implementation of marine mammal bycatch mitigation measures

41. Workshop participants noted the importance of social, economic and market drivers associated with marine mammal bycatch. Workshop participants agreed that these drivers should be considered in the development of technical guidelines for marine mammal bycatch mitigation.

42. Workshop participants also noted that it may be beneficial to build capacity to support the implementation of bycatch mitigation measures in small-scale fisheries and developing States.

RECOMMENDATIONS

43. FAO develop Technical Guidelines[1] on means and methods for prevention and reduction of marine mammal bycatch in fishing and aquaculture operations, supporting FAO's Code of Conduct for Responsible Fisheries and International Guidelines on Bycatch Management and Reduction of Discards, based on the information provided in this workshop. A peer review process to support the development of these proposed Technical Guidelines is recommended.

44. FAO facilitate a correspondence group drawn from the participants of this expert workshop to further develop a decision tree as part of the proposed technical guidelines.

45. FAO consider establishing a mechanism to facilitate the collection of information on the global implementation of the proposed Technical Guidelines, within the broader framework of the International Guidelines on Bycatch Management and Reduction of Discards, and include marine mammal bycatch prevention and reduction efforts in the bi-annual SOFIA publications.

46. FAO consider establishing a global capacity development programme to support developing States in the application of the proposed technical guidelines.

[1] Including social, economic, and market drivers.

APPENDIX 1

WORKSHOP AGENDA

Expert Workshop on Means and Methods for Reducing Marine Mammal Mortality in Fishing and Aquaculture Operations

20-23 March 2018, Rome, Italy

Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, Rome

DAY 1, Tuesday 20 March

09.00 - 09.15	Opening and welcome remarks FAO US NOAA Office of International Affairs
09.15 - 10.15	Introductions Objectives of the workshop COFI process and deliverables Presentation: Global marine mammal bycatch in fisheries through the US List of Foreign Fisheries: An analysis of fishing regions and gear types (*Nina Young)*
10.15 - 10.30	*Tea/Coffee break*
10.30 - 11.30	Presentation: The state of knowledge on marine mammal bycatch mitigation *(Tim Werner)*
11.30 - 12.30	Presentations: Leading and emerging bycatch reduction techniques for marine mammals Spatial management strategies for reducing fisheries mortality: What makes an effective protected area? *(Liz Slooten)* UK trials with acoustic deterrents in gillnet and trawls *(Simon Northridge)* Recent pinger trials, and other strategies for reducing marine mammal bycatch *(Sara Köngison)* Recent pinger trials, with multi-taxa implications (harbour seals and harbour porpoises) *(Arne Bjørge)*
12.30 - 14.00	*Lunch*
14.00 - 15.15	Presentations (continued): Leading and emerging bycatch reduction techniques for marine mammals Bycatch mitigation of pinnipeds with a focus on the efficacy of excluder devices in trawls *(Sheryl Hamilton*) New Zealand sea lion exclusion device (SLED) efficacy: uncertainty and implications for bycatch mitigation *(Bruce Robertson)*

Bycatch reduction in developing country fisheries *(Joanna Alfaro)*

A first approach to implement a bycatch mitigation strategy for Franciscana dolphins in Argentina *(Pablo Bordino)*

Reusable bottles as 1) acoustic alarms; 2) acoustic reflectors; and 3) solar-charged fluorescent lights, offer potential low-cost solution to marine mammal bycatch *(Per Berggren)*

Incentivising sustainable fisheries: ecolabeling and voluntary sustainability standards as globally applicable tools to reduce marine mammal bycatch *(Rohan Currey)*

Do's and dont's in eliminating bycatch in the conservation plan of a critically endangered species: vaquita *(Lorenzo Rojas-Bracho)*

15.15 - 15.30 *Coffee break*

15.30 - 17.00 Review/discuss plan for workshop outputs
- Workshop Report
- Bycatch Reduction Techniques – Achieving consensus
- Decision Tree – Refine and expand

17.30 - 19.30 FAO Rooftop Icebreaker reception

DAY 2, Wednesday 21 March

09.00 - 10.30	Assignment #1 instructions: Bycatch Reduction Techniques Table
	Breakout groups convene
10.30 - 10.45	*Tea/Coffee break*
10.45 - 12.30	Breakout groups reconvene
12.30 - 14.00	*Lunch*
14.00 - 15.00	Assignment #2 instructions: Decision Tree
	Breakout groups convene
15.15 - 15.30	*Tea/Coffee break*
15.30 - 17.00	Breakout groups reconvene

DAY 3, Thursday 22 March

09.00 - 09.30	Presentation of revised Techniques Table with discussion
	Review progress and challenges for Assignment #2
09.30 - 10.30	Breakout groups reconvene
10.30 - 10.45	*Tea/Coffee break*
10.45 - 12.30	Breakout groups meet
12.30 - 14.00	*Lunch*
14.00 - 15.00	Breakout groups meet
15.00 - 15.15	*Tea/Coffee break*

15.30 - 17.00	Presentations by breakout groups on decision trees; discussion Presentation of major recommendations collected during breakout groups; discussion

DAY 4, Friday 23 March

09.00 - 10.30	Presentation of revised decision tree and synthesis of overarching recommendations
10.30 - 10.45	*Tea/Coffee break*
10.45 - 12.30	Refine overarching recommendations on marine mammal bycatch reduction strategies collected during breakout groups
12.30 - 14.00	*Lunch*
14.00 - 15.15	Refine overarching recommendations on marine mammal bycatch reduction strategies collected during breakout groups
15.15 - 15.30	*Tea/Coffee break*
15.30 - 16.00	Wrap-up and next steps

APPENDIX 2

LIST OF PARTICIPANTS

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APPENDIX 3

BACKGROUND DOCUMENT

Means and Methods for Reducing Marine Mammal Mortality in Fishing and Aquaculture Operations

A review prepared for the FAO Workshop, March 20-23, 2018

Timothy B. Werner, Consortium for Wildlife Bycatch Reduction, and the Anderson Cabot Center for Ocean Life at the New England Aquarium, twerner@neaq.org

INTRODUCTION

This report provides a summary of techniques intended to prevent marine mammal bycatch. It focuses primarily on modifications to fishing gear or operations and includes an overview of time-area closures. The purpose of this report is to provide background material for a FAO technical workshop to review marine mammal bycatch reduction strategies in commercial fisheries and aquaculture operations.

The content of this report is based largely on three previous workshops convened by the Consortium for Wildlife Bycatch Reduction with support from the U.S. National Oceanic and Atmospheric Administration (NOAA) Fisheries: the 2011 workshop on marine mammal-gillnet bycatch, the 2013 workshop on marine mammal-longline bycatch, and the 2016 workshop on large whale entanglement prevention techniques. Many of the technical papers that emerged as outputs from these workshops have been published in scientific journals, including a special issue of *Endangered Species Research*, and a *Special Section of the ICES Journal of Marine Science*. Outputs have also been summarized in NOAA grant reports. Additional source material was accessed from the www.bycatch.org website, through online literature searches, and manuscripts in preparation by the author. This version includes additions made using information from participants at the FAO Workshop.

Using nomenclature from FAO reports, *bycatch* refers to incidental take of non-target species, both observed and unobserved, such as when whales drown or dolphins drop out of nets during gear hauling and may not be accounted for as bycatch. The techniques covered in this document focus on ones intended to avoid or prevent bycatch, rather than post-capture release by human intervention. The main objective is to avoid the mortality, suffering, stress and injury caused when marine mammals become entangled, hooked, or trapped in fishing gear. Human-mediated post-capture release can be difficult, potentially unsafe to marine mammals and the individuals attempting to free them, and provides no guarantee of post-release survival. Furthermore, a lot of bycatch goes unobserved, and while rescuing animals from small, critically endangered populations is important, it only helps a small percentage of bycaught animals.

Bycatch prevention techniques should not always be considered stand-alone strategies. In many cases, a combination of techniques is used to achieve the results intended. For example, time-area closures alone may not be adequate to reduce bycatch, but in combination with one or more gear modifications might attain the target level of reduction needed for maintaining or recovering the population.

The challenges and success in using particular techniques vary depending on the fishery, how they are implemented, and how the equipment is used and maintained. Many may not be appropriate for small-scale, non-industrial fisheries in developing countries. In these fisheries, there is less access to capital for modifying gear, and few incentives to change fishing gear or practices to reduce marine mammal bycatch. In fact, in some small-scale fisheries the capture of marine mammals can be considered catch with some consumptive use.

Changing fishing gear or practices to reduce marine mammal bycatch should adhere to at least two underlying principles:

1) Any change should not adversely affect target catch volumes, size classes, or quality that might threaten the continued viability of an otherwise sustainable fishery; and
2) Any change that assists in maintaining or recovering a particular population or species should not result in significant negative effects to other species or the ecosystem in which it resides.

ORGANIZATION OF THE REPORT

Each bycatch reduction technique covered in this report is described. Preceding the description is a brief summary of the concept behind the technique, the relevant fishing gear in which it might be considered, the marine mammal groups it targets, a quick summary of any available evidence of its efficacy, safety and operational considerations for fishermen, and economic implications. For more commonly used techniques (time-area closures and acoustic deterrents), the description includes additional information on guidelines for determining if they should be used, and strategic guidelines for implementing them within a fishery.

To better understand cases in which bycatch prevention techniques for marine mammals affect other taxa, sometimes included is information on the impact these techniques have on the bycatch of other non-target animal groups such as sea turtles and seabirds.

Also included is a discussion of switching gear, which involves changing the type of fishing gear altogether rather than simply modifying it, and voluntary actions under various codes of conduct or codes of practice. Not covered are discussions about effort reduction, catch shares, or market incentives that can also assist in achieving marine mammal bycatch reduction.

MARINE MAMMAL OVERVIEW

The species and populations identified for the purposes of the workshop are those currently recognized by the IUCN (2017) and listed in Appendix 3A. For each taxon, the corresponding FAO Fishing Area is provided as listed in the IUCN Red List. After consultation with IUCN reviewers the “vagrant” designation was ignored as some of the information was incorrect. Groups of marine mammals (e.g., Odontocetes) mentioned in the Gear Table (Appendix 4) are identifiable using the list of marine mammals.

The IUCN recognizes 129 species of marine mammals, or 215 species and subpopulations. Commonly, these are the polar bear, walrus, otters, seals, sea lions, whales, porpoises, dolphins, and sirenians (manatees and dugong). The most speciose group are the cetaceans, or the whales, dolphins, and porpoises. The IUCN Red List has 33 of these species listed as critically endangered, endangered, or vulnerable (IUCN 2017).

The Consortium for Wildlife Bycatch Reduction based at the New England Aquarium has compiled records of marine mammal bycatch for all fishing gear and aquaculture gear from 1990-2010, with gillnet records published in Reeves et al (2013), longline records in Werner et al (2015), and whale entanglement records in preparation. Remaining records have not yet been published, however they indicate that bycatch occurs with nearly every species of marine mammal, in all types of gear (with the possible exception of dredges), and in every part of the global ocean where the two co-occur. Perhaps the only species not prone to bycatch are polar bears and walrus. An absence of bycatch does not necessarily mean that it is not occurring or that the events are fewer than reported. Most bycatch incidents likely go unreported, especially in countries where there is limited monitoring. Even in countries with observer programs to monitor fishing operations, most bycatch events go unobserved or may otherwise be unaccounted for (e.g., large mysticete whale entanglements).

In general, prevention of marine mammal interactions with fishing gear has been developed in response to two different ways that marine mammals come into contact with fishing gear. Certain species, such as many of the pinnipeds, otters, and odontocete whales actively seek out the bait or target catch of fishing operations as feeding opportunities. Others become ensnared in fishing gear accidentally, perhaps because they are unaware of its presence or cannot avoid mobile gear in time. By far, the highest numbers of marine mammal bycatch occur as a result of the second category, and gillnets are considered the riskiest gear to most species (Perrin et al., 1994; Reeves et al., 2013). Sometimes, especially in cases involving depredation, the interactions do not necessarily lead to bycatch and their contribution to long-term reductions in population sizes may be negligible. Instead, they are more problematic for the economic loss to fishermen from catch or gear that can be damaged or lost.

FISHING GEAR

Names of fishing gear basically follow FAO's designations, and only use major headings. The principal and most common fishing gear designations are as follows:

- Hooks and Lines – including trolls and longlines
- Surrounding nets – including purse seines
- Trawls
- Traps – including pots and fyke nets
- Gillnets and entangling nets

Dredges are excluded in this report because of no identified marine mammal bycatch threat. This report does consider techniques used to prevent interactions between marine mammals and aquaculture operations. In some cases, those interactions cause bycatch through inadvertent conflicts, such as entanglements of right whales in mussel longlines. In other cases, marine mammals—pinnipeds in particular—remove fish from pens, and farm operators adopt a number of aggressive scare or culling tactics to reduce their incidence. Both cases involve techniques (e.g., acoustic deterrence) that are applied not only in aquaculture but in commercial fishing; therefore, their use in both types of gear were reviewed to help understand their overall efficacy.

Finally, bycatch occurs in shark or beach nets, which are essentially gillnets deployed in in eastern South Africa and Australia to reduce local shark populations, and control the incidence of shark attacks on bathers. Reference is included here to measures that have been tested to reduce bycatch of marine mammals in these nets, which occur frequently.

THE NEED TO SUPPORT MARINE MAMMAL BYCATCH REDUCTION

Countries and international agencies are signatories to a number of agreements that commit them to the goal of mitigating marine mammal bycatch (Appendix 3B). Justification for reducing the so-called collateral damage to marine mammals in fisheries include:

1) *Extinction risk*. The baiji (*Lipotes vexillifer*) is now likely extinct, in part due to mortalities that occurred in rolling hooks set by fishermen in the Yangtze River (Turvey et al., 2007). The vaquita (*Phocoena sinus*) now numbers fewer than 30 individuals since its population was decimated from bycatch in shrimp gillnets and illegal gillnets for totoaba (CIRVA, 2017). Mortality from entanglement in fishing gear is the principal threat to the recovery of the North Atlantic right whale (*Eubalaena glacialis*), with a population that has recently declined to fewer than 450 individuals. North Atlantic right whales have experienced an increase in entanglement rate and severity over the past ten years and reduced calving in the past several years (with none reported during the winter of 2017-2018 when most mom-calf pairs are observed).

2) *Maintaining ecological functions*. Many of these species provide critical ecological services within their environments including enhancement of primary productivity in surface and nutrient-poor waters, providing habitat for deep-sea species in the form of "whale falls," and regulating climate by fixing carbon through these two processes (Roman et al., 2014). Furthermore, as these authors point out, large whales support a global whale-watching industry valued at some $2 billion annually, have several important cultural and conservation values, and provide aboriginal hunters with food and other whale-derived products.
3) *Improving fisheries sustainability through practical changes*. Fishing industry regulators may be required under different laws to reduce marine mammal bycatch, and may resort to measures such as large-scale area closures or costly gear modifications that can challenge fisheries to maintain their economic viability.
4) *Loss/damage to gear and target catch*. Interactions between marine mammals and fishing and aquaculture facilities can lead to lost or damaged catch through depredation, damage to fishing gear such as tears in nets caused by cetaceans and pinnipeds, or lost pots that can be carried off and destroyed when dragged along the ocean floor by large whales. Derelict gear contributes to reduction in catch because it also is no longer available for fishing.
5) Supplying emerging markets for "certified" catch that can be consider safe for marine mammals.

NOTE

The term for individuals engaged in fishing in this document is "fisherman." Although this term generally is avoided in some studies because it is not considered gender neutral, the other widely used term "fisher" is considered less preferable because it refers to a species of North American mustelid. Although not all individuals who fish are male, the majority are, so the term is not entirely inappropriate.

BYCATCH REDUCTION STRATEGIES

The three general strategies described in this review for preventing marine mammal bycatch are: (1) Time-area closures; (2) Modifications to fishing gear or procedures; and (3) Gear switching. The review includes two tables listing examples of time-area closures and gear switching implemented expressly for the purpose of reducing marine mammal bycatch. A third table summarizes many of the studies of modifications to fishing gear or procedures discussed in this review, and was produced collaboratively with participants during the workshop (Appendix 4).

The ordering of strategies in this report begins with time-area closures followed by techniques involving modification to gear or operational procedures. These modifications are listed in alphabetical order using designations that for the most part are not standardized among researchers. These same designations are used for the table in Appendix 4, and this review can be consulted for more detail on table listings. Lastly is a section on gear switching and a discussion of Codes of Conduct/Practice.

Summaries of techniques involving trawl fisheries benefitted from a manuscript currently in review by Hamilton and Baker 2018.

TIME-AREA CLOSURES

Concept: Restricting the exposure of marine mammals to fishing gear reduces the number that become entangled or caught, so that bycatch no longer poses a risk to population survival or recovery.

Relevant fishing gear: all

Target marine mammals: all

Summary from evidence: Undoubtedly, if located in the most critical habitats, well designed, and well enforced, time-area closures can reduce bycatch within their borders. What is generally lacking in the implementation of time-area closures is the recognition that these areas or network of areas must encompass sufficient habitat and eliminate the bycatch risk. In some cases, to be truly effective and substantially reduce risk, an area or network of areas would encompass such a wide geographic extent that it can threaten the persistence of the fishery. Fishermen are generally opposed to closing off access to fishing grounds. Furthermore, redirecting fishing effort to other areas carries a risk of concentrating fishing effort into smaller or more densely fished areas that might result in higher bycatch than in the absence of time-area closures.

Safety/operational considerations: Generally low, unless higher gear densities lead to more gear conflicts that can increase the strain on gear during retrieval when it becomes entangled in another fisherman's gear.

Economic concerns: Areas large enough to achieve their bycatch reduction targets may significantly reduce fishing revenues (at least in the short term), and require costly allocation of adequate enforcement and monitoring resources from regulators.

Description: Time-area closures ban or restrict fishing within all or a subset of a particular fishing zone, permanently or for a set period (FAO, 2011). In terms of bycatch mitigation, a range of spatial management categories exist from strict "no-take areas" which prohibit all fishing, to areas where only certain fishing gear or modified gear is permitted (i.e., area-gear closures), during certain periods of the year. For example, in much of Cape Cod Bay (Massachusetts, United States), no pot gear may be set between January 1 and April 30 (DoC, 2013). Some areas may be temporarily closed through a dynamic process, only going into effect when a particular level of bycatch is reached or exceeded, or when the presence of bycatch-prone species reaches a certain threshold during fishing operations. Such conditional regulations include the 'consequence closures' to protect harbor porpoise off the eastern United States, banning gillnets when the Potential Biological Removal (PBR) target is reached (NOAA 2010). Similar regulations in South Australia enact area closures when trigger levels of marine mammal bycatch are reached (AFMA, 2014). Under the Atlantic Large Whale Take Reduction Plan, the U.S. National Marine Fisheries Service (NMFS) established Dynamic Area Management closure zones any time an endangered North Atlantic right whale was spotted within certain areas, although this measure is no longer used as a fishery management tool.

Time-area closures to restrict gillnet fishing have been established in several countries in response to concerns about marine mammal bycatch, including Australia, New Zealand, Mexico, the United States, and in Europe (*Table 1*).

Area restrictions may be considered useful when high bycatch consistently occurs in the same areas and seasons (Murray et al., 2000; FAO 2011). Of course, it is often the case that areas used seasonally by marine species are geographically broad and dynamic, suggesting that restricted zones would need to be sufficiently large or flexible to be effective.

Despite their widespread use and prevalence as a bycatch reduction measure for fisheries managers, few studies have quantified the effect of these closures on the bycatch species or populations for which they were established. Gormley et al. (2012) used capture-recapture data of Hector's dolphin in the vicinity of a small reserve in New Zealand to analyze whether the reserve's establishment and its ban on the use of gillnets had any measurable effect on the local population of Hector's dolphin. Using a Bayesian statistical model, they concluded that the reserve increased the mean survival probability for the resident population, but that the reserve size was insufficient for contributing to recovery of the overall population. Slooten (2013) modeled the potential for population recovery of this endangered species throughout its entire range under the existing time-area management system, and concluded that the present scheme (reserve locations, sizes, and management regimes) would not likely lead to population recovery in Hector's dolphin, nor prevent the species from continuing its decline. In reviewing the history of efforts to conserve Mexico's endangered vaquita porpoise, Rojas-Bracho and Reeves (2013) discussed the impact of protected areas and concluded that they needed to encompass the entire range of the vaquita to completely eliminate bycatch and give the remaining population a higher probability of recovering. The consensus of these three studies is that despite adopting time-area (and sometimes time-area-gear) closures as the principal management response for reducing bycatch of marine mammals, the ultimate conservation benefit of population recovery was not fully realized.

Some outright gillnet bans and area closures exist in several states in the United States. None, or at least only a small percentage of these closures, seems to have been created expressly for reducing marine mammal bycatch (Harrison 1995).

Table 1. Examples of gillnet time-area closures established to avoid or reduce marine mammal bycatch. U.S. examples use lists of bycatch species current as of 2017. If a gillnet fishery is not included, it means that time-area closures are not part of strategy for managing bycatch (Werner et al., in prep.).

Country	Fishery and/or target species	Targeted Marine Mammal(s)[2]	Type of Area Restriction	Reference
Australia	Southern and Eastern Scalefish and Shark Fishery	Australian sea lion (*Neophoca cinerea)*	Year-round closures of varying distances (11nm maximum) from seal colonies; a marine mammal protected area as part of the Great Australian Bight Marine Park with year-round gillnet fishing bans in a portion of the park and a six-month closure in the rest; regional "trigger" closures based on bycatch mortality figures	AFMA, 2010; Hamer et al., 2011
Australia	Southern and Eastern Scalefish and Shark Fishery	"Dolphin" (all species of dolphin occurring in the area, known to include the Short-beaked common dolphin (*Delphinus delphis*) and Bottlenose dolphins (*Tursiops* spp.) (E. Raudzens, AFMA, *pers. comm*.)	A 27,239 km^2 of the S. Australia coast closed to gillnet fishing (while still allowing hook fishing up to a maximum per permit holder of 400 hooks at any one time)	AFMA, 2011
New Zealand	Multiple species	Hector's dolphin (*Cephalorhychus hectori*)	As a supplement to two small protected areas (Banks Peninsula and North Island west coast), year-round bans on using set nets to 7 nautical miles offshore off the North Island west coast, and to 4 nautical miles offshore off the South Island east and south coasts. Off the South Island west coast the ban is in place for three months of the year and to only 2 nautical miles offshore.	Slooten, 2013
Mexico	Kelp bass and sharks	Gray whale (*Eschrichtius robustus*)	Gillnets may not be set in the lagoon channels of the El Vizcaíno Biosphere Reserve between December 15 and April 15	Instituto Nacional De Ecología, 2000
Mexico	Shrimp and multiple fin fish species	Vaquita (*Phocoena sinus*)	A vaquita refuge was federally declared in 2005 in the western portion of the upper Gulf of California. Gillnet and trawl fishing are banned in two core zones of the reserve. Since 2015, a complete gillnet ban was declared in the upper Gulf within critical vaquita habitat with the exception of curvina and sierra fishing.	Rojas-Bracho and Reeves, 2013; CIRVA (V), 2014

[2] For US fisheries, the marine mammal species listed may only be those for which bycatch has been observed to occur in gillnet gear. Other fisheries, such as for salmon in Alaska and Washington, may also produce marine mammal bycatch (Moore et al., 2009).

Country	Fishery and/or target species	Targeted Marine Mammal(s)[2]	Type of Area Restriction	Reference
US (States of CA, OR, and WA)	CA Thresher Shark/Swordfish Drift Gillnet (≥14 in. mesh) Fishery	CA sea lion (*Zalophus californianus*), Minke whale (*Balaenoptera acutorostrata*), Humpback whale (*Megaptera novaeangliae*), Sperm whale (*Physeter macrocephalus*), Long-beaked common dolphin (*Delphinus capensis*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), Northern elephant seal (*Mirounga angustirostris*), Northern right whale dolphin (*Lissodelphis borealis*), Risso's dolphin (*Grampus griseus*), Short-finned pilot whale (*Globicephala macrorhynchus*) Short-beaked common dolphin	As informed by the Pacific Offshore Cetacean Take Reduction Team, the use of drift nets is restricted in various parts of the EEZ off California. Additional area restrictions, both year-round and seasonal, are mandated by each of the three states. Washington State prohibits the use of this gear. (See text regarding closures in State waters).	NMFS, 2012 and 2017 List of Fisheries - http://www.nmfs.noaa.gov/pr/pdfs/fisheries/lof2012/ca_thresher_shark_swordfish_drift_gillnet.pdf; http://www.nmfs.noaa.gov/pr/interactions/fisheries/table1/wcr/ca_thresher_sword_dgn.html); PFMC 2016
US (east coast)[3]	Mid-Atlantic Gillnet Fishery (multi-species); Northeast Sink Gillnet (multi-species), Northeast anchored float gillnet fishery, Northeast drift gillnet fishery, Southeast Atlantic gillnet fishery, Southeastern U.S. Atlantic shark gillnet fishery, North Carolina Inshore Gillnet Fishery, High Seas Atlantic Highly Migratory Species (HMS) Fisheries (Drift gillnet component)	Bottlenose dolphin (*Tursiops truncatus*), Short-beaked common dolphin, Risso's dolphin (*Grampus griseus*), Gray seal (*Halichoerus grypus*,) Harbor porpoise (*Phocoena phocoena*), Harbor seal (*Phoca vitulina*), Harp seal (*Pagophilus groenlandicus*), Hooded seal (*Cystophora cristata*), Humpback whale, North Atlantic right whale (*Eubalaena glacialis*), Fin whale (*Balaenoptera physalus*), Minke whale, Long-finned pilot whale (*Globicephala melas*), Short-finned pilot whale (*G. macrorhynchus*), Atlantic White-sided dolphin (*Lagenorhynchus acutus*), Atlantic spotted dolphin (*Stenella frontalis*);	Area and gear restrictions as mandated under the Bottlenose Dolphin TRP, the Atlantic Large Whale Take Reduction Plan, and by state fisheries regulations	NMFS 2012 and 2017(List of Fisheries - http://www.nmfs.noaa.gov/pr/pdfs/fisheries/lof2012/midatlantic_gillnet.pdf; http://www.nmfs.noaa.gov/pr/interactions/fisheries/table2/midatl_gillnet.html); NMFS 2010

[3] Various fisheries combined. Not all marine mammal species might be expected to occur as bycatch in each fishery listed here, but in the combined total.

Country	Fishery and/or target species	Targeted Marine Mammal(s)[2]	Type of Area Restriction	Reference
		(Note: The Northeast Sink Gillnet Fishery had previously listed spotted dolphins, striped dolphins, killer whales, and false killer whales.)		
Finland	Commercial and recreational gillnet fisheries; the former primarily targeting vendace (*Coregonus albula*) (Salmi et al., 2000)	Saimaa ringed seal (*Pusa hispida saimensis*)	Gillnet fishing is banned between April 15 and June 30 in a > 2000 km^2 area of freshwater Lake Saimaa, based on a 2011 Government Decree that expanded the area from a smaller one established in 1982. There is also an area of the lake covering approximately 1741 km^2 in which certain types of gillnets, trammel nets, multi-filament nets, and other gear are banned year-round beginning in 1999, and as currently defined by another 2011 Government Decree (Niemi et al., 2012)	Niemi et al., 2012; Salmi et al., 2000
Germany		Harbor porpoise	Small cetacean sanctuary (west of the Sylt and Amrum Islands), within the Wadden Sea of Schleswig-Holstein National Park. Some fishing gears still permitted, including gillnets with a maximum height of 130 cm and a maximum mesh size of 150mm	Proelss et al., 2011; A. Pfander (*pers. comm.*)

In considering the ultimate goal of conserving or recovering a species or subpopulation, it is important to determine whether quantitatively measurable management targets are met (e.g., monitoring needs to determine whether bycatch is below the PBR level in the short-term, and below levels approaching zero in the long-term). The minimum data requirement for designing a marine mammal protection area is the distribution and movements of the marine mammal population, particularly when the situation is urgent, as is the case for highly endangered populations or high levels of fisheries mortality. Data on the distribution and movements of the fishery are also helpful, bearing in mind that most fisheries are highly dynamic. Areas with a high level of overlap between marine mammals and fishing operations that cause marine mammal mortality may shift as economic pressures on the fishery change. Research tools to help optimize the design of closed areas include the methods used for Australian sea lions (*Neophoca cinerea*), such as modeling biological (and economic) cost/benefit of different management options (Goldsworthy 2007), and Hector's dolphins (Slooten and Dawson, 2010; Slooten and Davies, 2011). The data needed to assess the effectiveness of closed areas, in reducing bycatch to sustainable levels, include marine mammal distribution, abundance, survival rates, population viability, year-to-year variability, distribution of fishing effort, and level of bycatch.

While area closures can reduce marine mammal bycatch, at least within critical habitats where they tend to aggregate, the ultimate goal of bycatch reduction measures should target whole populations or species. Local gains in bycatch reduction must be measured in terms of their contribution to the overall conservation or recovery of target populations and species throughout their ranges. Bycatch reduction gains within a closed zone can have local conservation benefits but ultimately may not realize the intended objective if the closure, in combination with other time-area closures and/or bycatch reduction measures, fails to lead to species recovery. The few studies and reviews carried out so far to examine the contribution of time-area closures on bycaught marine mammals have concluded that local fishing restrictions did not produce their overall intended effect, and instead in some cases may simply have redirected fishing effort to other areas, even leading to higher bycatch rates (O'Keefe et al., 2014; Orphanides and Palka, 2013). This observation is not surprising given the generally large geographic ranges of marine mammals, the lower likelihood that protected areas will assist the maintenance or recovery of pelagic species versus reef-associated ones, and the need to protect a large percentage of a pelagic species' geographic range in order to produce measurable population benefits (Kaiser, 2005). Furthermore, fisheries closure areas tend to be static in space and time, while marine mammal occurrence can be dynamic, due to effects from variable oceanographic and ecological processes (Grantham et al., 2011) or attributable to consequences of climate change (Gaines et al., 2010) and human disturbance within marine mammal habitats (Hartel et al., 2015). The United States tired using dynamic area closures, where the location of whale sightings triggered implementation of ship speed reductions and fishing restrictions, including removal of gear. However, this measure was abandoned for fisheries after several years when decision makers determined it was unworkable. Taken together, these observations should not be used as an argument against time-area closures as a marine mammal bycatch reduction tool but call attention to the need to carefully design and implement them so that they achieve their desired effect.

In summary, to conserve or recover a species or population, time-area closures need to be of appropriate size to meet the management objective, located in the right areas, effectively managed to remove principal threat, avoid introducing new threats, and consider the dynamic nature of habitat use by marine mammals over time (see Gerrodette and Rojas-Bracho, 2011; Gormley et al., 2012; Slooten, 2013).

Implementation Considerations

If adopting time-area closures as a bycatch reduction strategy, several important considerations should factor into the decision to use them, and in how they are implemented.

1) Sufficient information should exist in order to identify the most critical habitats where marine mammals and fishing gear co-occur. These include:
   - Distribution of marine mammal species
   - High use/density areas
   - Seasonal/daily movements
   - Locations where bycatch occurs
   - Life history of target and bycatch species
   - Medium term occurrence changes (e.g., North Atlantic right whales occurring with less frequency in habitats such as the Bay of Fundy where they used to be observed on a regular basis)
   - Where and when fishing occurs, and its spatially dynamic nature
   - The bycatch reduction benefits of time area closures, and risk assessment to help evaluate the contribution of these areas to reducing bycatch
2) Sufficient capacity to monitor and enforce the closed areas and the use of any mandated gear restrictions. A common approach involves the use of fisheries observers for monitoring bycatch in order to evaluate the effectiveness of closure strategies. Fisheries jurisdictions should also have appropriate legislative and regulatory mechanisms in place to support time-area closures, and have adequate capacity and commitment for enforcement. Lastly, capacity to conduct outreach should be available for disseminating information about area closures/restrictions that reaches the fishing sector.
3) It is likely not sufficient to protect marine mammals only within geographically concentrated closures if the population has a much wider geographic distribution. An analysis of the bycatch reduction resulting from the establishment of one or more closed areas should evaluate if they are meeting designated bycatch reduction targets so that the marine mammal population as a whole is sustained or recovering.
4) Closed areas risk displacing fishing effort to other areas, possibly concentrating fishing effort and increasing bycatch. This risk needs to be accounted for and monitored.
5) The use of a time-area closure strategy is an appropriate part of a bycatch mitigation strategy under several circumstances that include, among others:
   - When bycatch must be reduced to zero, such as with highly endangered marine mammals concentrated within relatively small areas
   - There is adequate capacity for monitoring and enforcement.
6) Multiple fisheries contribute to bycatch of a focal marine mammal, so the contribution of all relevant fisheries must be calculated.

MODIFICATION TO GEAR OR OPERATIONAL PROCEDURES

Acoustic Deterrent Devices (ADDs)

Concept: Introducing particular sound sources or attaching devices that can enhance detection of fishing gear using echolocation (with cetaceans) will alert marine mammals to avoid a fishing area, leading to reduced interactions between them and fishing operations
Relevant fishing gear: Mainly gillnets, trawls, and aquaculture, but potentially other gear
Target marine mammals: Cetaceans and pinnipeds
Summary from evidence: Cetaceans and pinnipeds show behavioral responses to acoustic signals, although it is dependent on the species involved, underwater conditions that influence sound propagation, the type of acoustic device used, and the frequency and magnitude of the sound. There is some evidence that long-standing concerns about animals becoming sensitized to sound or being permanently excluded from critical habitats need to be taken seriously. Furthermore, high output devices may affect marine mammal hearing and potentially impact their survival. Owing to these and other factors that influence the effectiveness of these devices or their potential downsides, before acoustic deterrents are deployed considerable evaluation is required to ensure they achieve the desired effect.
Safety/operational considerations: Minimal, although some fishermen in the eastern U.S. report that some pingers can "explode" under pressure with the incursion of saltwater into the electrical components.
Economic concerns: Equipping fishing gear with acoustic devices can range from several hundred to thousands of dollars, which may be cost-prohibitive in some fisheries. There is also the added cost of maintenance (e.g., changing batteries) that may be required frequently in all but the newest models.

Description: Acoustic deterrents refer to a range of devices that emit sound using electrical or mechanical means, or are designed to be acoustically reflective to echolocating cetaceans. They may be deployed on or near to fishing gear, and include categories of devices referred to as pingers, acoustic harassment devices, passive acoustic devices, and seal-scarer devices.

The units that actively produce sound span a range of power outputs (measured in decibels (dB)), audio frequencies (Hz), and the periodicity of sound emission (its duty cycle, which may be regular, random, or triggered such as by echolocating cetaceans). Passive devices have also been proposed and tested as a way to alert species that use echolocation to the presence of gear. Still other devices mimic the noises produced by predators of marine mammals. Finally, firearms and explosive devices are used to scare away marine mammals by producing noise in air or water, and may cause pain or bodily injury when animals are hit by projectiles or detonated explosives.

Acoustic deterrents are the most widely researched and implemented technique for deterring marine mammal interactions with fisheries, so an exhaustive research review is not provided here. Dawson et al (2013) produced an intensive review of pingers, and summaries of studies using pingers are available through a search of the bycatch.org database by using the search term "acoustic deterrents."

Types of Acoustic Deterrent Devices (ADDs)
Active acoustic deterrents can be categorized according to the intensity of disturbance they are intended to produce on their animal targets.

Pingers tend to be relatively small, cylindrical shaped units that produce sound at different frequencies but generally in the 3-70kHz range, and less than 180dB (re 1 pPa @ 1 m). They are most commonly used as a device for avoiding bycatch of small cetaceans, harbor porpoise in particular, in gillnets.

Acoustic Harassment Devices (AHDs) generally use higher sound outputs to keep animals at bay, often by inflicting pain or discomfort. Although the cut-off point between what constitutes a pinger or AHDs is somewhat arbitrary, devices of 180dB or higher are sometimes classified as AHDs to distinguish them from pingers (Long et al., 2015). AHDs are frequently used in aquaculture operations to keep seals and sea lions from preying on farmed fish. Also known as “seal scarers,” these devices are intended to harass using sound. Several field evaluations of different versions of these devices have shown a temporary deterrent effect, however eventually the seals exposed to the sounds overcame their initial avoidance of the ensonified area--that is, they habituated to the noise (Geiger and Jeffries, 1987; Gearin et al., 1988; Fjälling et al., 2006).

Predator or other species playbacks. *Predator sounds*, which mainly include the playback of killer whale sounds, showed some potential for deterring particular marine mammal species, but they can also affect the behavior of target fishes, leading to reduced target catch (see, for example, Doksæter et al., 2009).

Passive acoustic deterrents use air-filled or metallic components incorporated into fishing gear to increase their detection by echolocating cetaceans. While this technique is relatively cheap and easy to implement, and targets echolocating marine mammals that do not depredate bait or catch, it is generally considered not effective (*see* Dawson 1994).

Dolphin Dissuasive Devices may reduce common dolphin bycatch in pair trawl nets; however, further testing is needed using a sufficient number of control tows (Northridge et al., 2011; De Carlo et al., 2012). There is no indication that pingers deter bottlenose dolphins from entering trawl nets, and operational noise may outweigh any deterrent affect from pingers (Allen et al., 2014). *Cetasaver* pinger trials resulted in 70% reduction in common dolphin bycatch; however, sample sizes (based on number of observations) were not large enough to obtain a statistically significant result so more testing is required (Morizur et al., 2007, 2008). Target catch rate was not affected, however the background noise of trawl operations was an issue. In trials involving the *AquaTech 363 Interactive Pinger*, common dolphins exhibited evasive behavior, however subsequent trials showed the device was not effective in deterring interactions in trawl gear (van Marlen, 2007).

Deterrence Strategy

Continuing to the present day, the intention of active acoustic deterrents has been to displace animals from the vicinity of fishing or gear while gear was deployed in the water. This displacement has raised concerns regarding habitat exclusion, a potentially serious problem if the area ensonified deters a population of marine mammals from using critically important habitat. Optimally, a preferred strategy would be to create an alert response that warns a marine mammal to the presence of fishing gear so that it avoids it without sustained disruption to its behavior prior to hearing the sound. For example, a migrating whale might alter its path slightly away from fishing gear upon hearing an alert sound without causing major alteration to its migratory route. To date, no examples exist of devices that use an optional frequency, output, and duty cycle to achieve a targeted alert response, although this is a focus of some current research (see, for example, Culik et al., 2015 on the use of harbor porpoise vocalizations).

Evaluating the potential use of acoustic deterrents

Owing to the relatively widespread use and interest in acoustic deterrents, we provide the following checklist to help identify circumstances in which acoustic deterrents should receive consideration as an effective and advisable strategy for reducing bycatch of marine mammals.

1) *Is there evidence to support or refute that the marine mammal will exhibit an appropriate alert or area avoidance response to the deterrent?* An extensive body of research from both fishery and behavioral trials, as well as monitoring of marine mammal bycatch over time in fisheries, clearly indicate interspecific differences in area avoidance response. The differences range from near total area displacement to attraction. The issue with pinnipeds is mainly one of depredation, and most of the acoustic deterrents with this group have been of higher sound outputs (acoustic harassment devices). Habituation appears to be the norm rather than the exception with these animals. There is really no evidence to date that acoustic deterrents work at all for Mysticete whales, and for Odontocete cetaceans it varies depending on the species (see Appendix 4).

   Producing evidence that acoustic devices have a deterrent effect on the population of concern can be tested through: (1) behavioral trials to determine if populations avoid the areas ensonified; (2) fisheries trials comparing bycatch between ensonified gear and non-ensonified gear; or (3) fisheries observer data showing that the use of acoustic deterrents has reduced bycatch across the fishery compared to when deterrents were not used.

   (a) *Will population or environmental consequences outweigh likely bycatch benefits?* Evaluations should be carried out to examine if:
   (b) the area to be ensonified is of a size or type that would likely exclude the population from critical habitat. An optimal acoustic deterrent would be one that provokes an alert response in a marine mammal about the need to avoid the immediate vicinity of a fishing operation without significantly altering its travel path or habitat use. However, it is difficult to create a sound that acts only to alert without also evoking an avoidance response.
   (c) pingers might cause animals to aggregate, depending on the density and configuration, into areas that might not be their optimal habitat or where the threat is greater.
   (d) the deterrent will have lethal or sub-lethal effects on the population such as causing pain and suffering. ADDs may impair hearing and cause pain in pinnipeds, and ensonified environments might decrease foraging success.
   (e) the size of the population is so low (endangered) that area displacement could force it to move into areas where it would be exposed to other threats (Forney et al., 2017).
   (f) ADDs increase interactions with other non-target marine mammals such as through the “dinner bell effect”, in which depredating species (e.g., some pinnipeds and delphinids) associate the sound of the devices with a feeding opportunity. This may be managed, at least with pinnipeds, by increasing pinger frequency so that the ADD output is outside their peak hearing frequency but within that of cetaceans.
   (g) the population of animals is becoming habituated to the deterrent’s sound and no longer avoids the area where fishing occurs. Evidence can be collected from one or more field studies on habituation over time. Animal behavior studies can show less aversive response to pingers over time (e.g. Cox et al., 2004), but within fisheries studies it does not appear to be an issue where studied (e.g., Palka et al., 2008; Carretta and Barlow, 2011). It is important to keep monitoring the possibility that animals are becoming habituated, except for cases in which the species are known depredators (e.g., bottlenose dolphins).
   (h) other adverse consequences to other species or the local environment are likely to occur.

2) *Might other sources of background noise, their persistence, or physical characteristics in the environment affect the audibility of ADDs?* Repeated exposure to high intensity sounds, or the emission of sound within environments already saturated with noise from ship traffic, seismic surveys, depth sounders, fish finders, naval sonar, etc., can desensitize individual marine mammals to perceive acoustic deterrents (NRC, 2005). Background noise and propagation conditions will affect the range over which sounds can be detected.

3) *Will use of the deterrents effect fish catch CPUE and target sizes?* Acoustic deterrents generally have not reduced target catch levels, but this should be determined on a case-by-case basis.

4) *Is the fishery operationally capable of using and deploying pingers effectively and practically?* This requires an ability to afford pingers, careful guidelines on how to operate and deploy them, proper maintenance, and sufficient monitoring and enforcement capacity.

   As with all fishing gear, deterrents require maintenance. Most devices are about the size of a small carbonated beverage can, and should be checked regularly to ensure they are functioning properly. Bat detectors or hydrophones can measure the frequency of units inaudible to the human ear, and some pingers now include LEDs that flash to indicate their batteries are operating.

   Fishermen report battery life and the relative high cost of pingers as their main concerns. Individual units can cost between approximately US$100 - $1000s, and some batteries can last over two years but less if emitting sound more frequently. Gillnets require several pingers along a net string at varying intervals (e.g., at 50m spacing), requiring fisherman to have multiple units. In the northeastern U.S., fishermen reported devices exploding when deployed in deeper waters. To address this problem, newer units have been redesigned.

   When explosive devices are used as acoustic deterrents, special safety precautions are required. Due to their potential to kill or injure the animals targeted, the use of these devices should be discouraged.

   The interval of pinger deployment along a net can result in different levels of bycatch. For example, Larsen et al. (2013) increased pinger spacing to more than double the specified regulatory requirement for gillnets (every 200m), and recorded no bycatch of harbor porpoise, whereas increasing the spacing by an additional >100m resulted in bycatch. Where fixed fishing gear is especially dense and acoustic deterrents effective, the entire fishing area may be ensonified, excluding animals entirely from those areas. This can be a problem if the habitat is critical to the population's survival. In addition, under areas of high fixed gear density, the area avoidance effect in one set of gear may redirect an animal towards another set of gear or a gap in the sound coverage area, which can potentially increase bycatch. With *active deterrents*, such as pingers and AHDs, variability in sound intensity, frequency, duty cycle, and directionality can produce different results. When units do not perform according to manufacturer specifications even though they may be appropriate for their target marine mammal population, bycatch reduction targets may not be met.

5) Pingers are never 100% effective, and results observed in experiments may be different than those observed in fisheries (Dawson et al., 2013). It is important to account for these differences when using acoustic deterrents to achieve a target rate of bycatch reduction. Unfortunately, there is no guarantee that a successful trial from one fishing area will translate to success in another, and as is often the case, experimental results achieve higher bycatch reductions than actual fishery operations.

6) The deterrent effect will vary depending on the type of device used and how it is deployed.

Finally, the species of concern may not be one for which acoustic deterrents have been trialed. In those instances, one option is to carry out a relatively quick and inexpensive behavioral trial to see if the local animal population a sound source when it is on versus off (see, for example, Carlström et al., 2009). If no area avoidance effect is observed, the use of another bycatch reduction technique is needed. Acoustic deterrents can also work in synergy with other techniques, such as time-area closures, to mitigate the potential downside of habitat exclusion (van Beest et al., 2017).

There have been almost no evaluations of acoustic deterrents for reducing bycatch of other animal groups. With seabirds, one study did show a reduction in bycatch of the Common Murre (*Uria aalge*) (Melvin et al., 1999) but not the Rhinoceros auklet (*Cerorhinca monocerata*).

Backdown Procedure

Concept: Altering the hauling process can facilitate the escape of dolphins before they become caught and killed in the net
Relevant fishing gear: Purse seines
Target marine mammals: Small cetaceans
Summary from evidence: This technique was developed in the eastern tropical Pacific Ocean where schools of dolphins are intentionally set on in tuna purse seine fishing operations. It has been in widespread use there for decades and is attributed with having significantly reduced bycatch of several dolphin species. To be effective the backdown procedure must be used together with a dense-meshed panel in one portion of the seine (Medina panel) and support teams that corral dolphins in the direction of this panel.
Safety/operational considerations: Some mortality of fishermen has been reported as this process requires fishermen to enter the water and assist in corralling dolphins down the backdown channel.
Economic concerns: Requires support from small outboard boats and crew to assist in the hauling process

Description: The backdown procedure is used by purse seine operators to facilitate the escape of dolphins that have been intentionally encircled to capture tuna. The backdown occurs after the majority of the net is on board. At this point net retrieval is stopped, the net is tied to the vessel and the engine is put into reverse. This creates a water current that causes the net remaining in the water to form a long channel. The water current also pulls the end of the channel under water providing an area for dolphins to escape (Bratten and Hall, 1996), which is facilitated by herding using rafts and swimmers, and skiffs to maintain the shape of the seine net (NRC 1992). Together with the use of the Medina Panel, a small-mesh net liner at the apex of the net, this technique has been attributed with major reductions in several species of dolphins in the eastern tropical Pacific.

Outside the eastern tropical Pacific Ocean, fishermen do not intentionally encircle dolphins with purse seine nets to capture tuna. Therefore, there is no evidence that the backdown procedure is used or that it is effective in any other ocean or in conditions differing from those in the eastern tropical Pacific Ocean. The western and central Pacific Ocean and the Indian Ocean regional fishery management organizations have adopted conservation and management measures prohibiting intentional encirclement of cetacean to capture tuna and require the use of safe handling and release protocols if animals are accidentally encircled.

Gear with reduced breaking or hook bending strength

Concept: Weaker gear components can facilitate the escape of marine mammals before serious injury occurs, while retaining sufficient target catch

Relevant fishing gear: Gillnets, pot ropes, longlines

Target marine mammals: Cetaceans

Summary from evidence: Longline hooks made of certain metals and at specific diameters can be straightened by non-target marine mammals; however, the challenge is to ensure that these hooks are not easily bent by larger individuals of target catch species, reducing fishing revenues. Post-hooking survivorship must be taken into account. Gillnets constructed from weaker twines might facilitate the release of entangled cetaceans. Some large whale species, such as North Atlantic right whales, are more likely to break free from ropes of lower breaking strength used in pot fisheries.

Safety/operational considerations: Weaker hooks can help longline fishermen avoid the need to release small cetaceans hooked on their lines, or to cut the lines. Some whale-release rope designs require additional—though minimal—time to be constructed, such as when splicing in braided sleeves of reduced breaking strength. Some lobster fishermen express concern that ropes prone to breaking pose a safety risk if they snap during hauling. If reduced breaking strength rope breaks after contact with a whale, severed ropes might produce more derelict gear. At the same time, however, there would be a reduced likelihood that bottom gear would be carried by an entangled whale to a location other than where it was set, so pots and groundlines (where used) should be easier to relocate.

Economic concerns: Animals that die or escape from gillnets are not hauled up with the gear, so it is difficult to quantify whether this technique is having its desired effect, and damaged nets require repairs or replacement which can be costly. "Whale-safe" hooks do not solve the problem of depredation on bait or catch. At least one whale-release prototype rope can be produced at the same cost as regular endline.

Description: Portions of fishing gear can be made weaker to facilitate the escape of marine mammals that become entangled or hooked in them.

Decreasing the breaking strain of gillnet parts

a. *Decreasing twine diameter*

The rationale for considering the use of thinner twines is to facilitate entangled marine mammals breaking free, while retaining target catch. A comparison of gillnets using twines with 2mm and 4mm (standard) in a Baltic cod fishery showed that the thinner-twined nets caught more fish (Holst et al., 2002). Thin twine monofilament nets (0.4 mm twine diameter, 90 mm mesh size) reduced bycatch of harbor porpoise and seals in the North Sea and West of Scotland gillnet fisheries when compared to thick (0.6 mm twine diameter, 267 mm mesh size) monofilament nets (Northridge et al., 2003). However, nets of variable mesh size were used in this trial so quantifying the degree that twine versus mesh size contributed to bycatch reduction would be necessary to see if twine size was an explanatory variable in the differences recorded.

Thinner twine will tend to increase the flexibility of gillnets, which often results in higher catches of commercial species, and sometimes affects how well it catches desired size-classes of target species (Gray et al., 2005; Grati et al., 2015). Assuming marine mammals are better able to break free from thinner twined gillnets, uncertainty remains regarding their health and survival following the encounter (i.e., unaccounted for mortality), as well as the possibility that thinner twines would increase unaccounted for drop-outs of bycaught marine mammals during net hauling, both actions resulting in lower than actual reported bycatch. This approach could result in greater damage to nets, and likely increase the net repair and replacement costs by fishermen. Another outcome might include some reduction in target catch as a function of decreased net area. Weakening gear components should increase the risk of breakage, resulting in greater loss of gear as it becomes separated from the haulable portion of gillnet strings. This could generate additional "ghost gear" that might still pose an entanglement risk, and introduce more plastic debris in the ocean with consequences to the health of marine species and ecosystems.

b. Weak links

In the United States, regulatory measures under the Atlantic Large Whale Take Reduction Plan require that all gillnets be rigged with anchors and buoy line weak links with a maximum breaking strength of 1100lb, placed as close to each individual buoy as operationally feasible and net panel weak links with a maximum breaking strength of 1100lb in the centre of the floatline section on each 50-fathom net panel or every 25 fathoms on the floatline for longer panels (*see*: http://www.greateratlantic.fisheries.noaa.gov/Protected/whaletrp/). There are areas where these requirements are excepted, and in at least one location (coastal North Carolina) the requirement is for a link with breaking strength of 600lbs.

Lowering the breaking strength of some or all portions of pot ropes

a. Weak links

For pot fishing gear, regulatory measures under the Atlantic Large Whale Take Reduction Plan require weak links be placed below the buoy at the uppermost portion of the endline. These may consist of hog rings or plastic rings that are narrowed in diameter to break at a target load, between 200 and 2000lbf, and generally 600-1500lbf.

There is no evidence to support that weak links incorporated into pot (or gillnet) gear have reduced either the incidence or severity of large whale entanglements off the east coast of the U.S. A recent study concluded that no management measures implemented in this region between 1998–2009 appear to have reduced the death of large whales from such entanglements (Pace et al., 2014), while serious injuries and mortalities continue to exceed the allowable rate established by regulators (Knowlton et al., 2012).

After nearly two decades since weak links became required under U.S. regulations, it is still unclear whether they function as intended. Entangled whales have been observed carrying weak links, perhaps suggesting they either did not achieve their intended objective. It is also possible that they have helped avoid more entanglements. Weak links can be a relatively low-cost method, so if they were effective in helping to release entangled whales they may be particularly appropriate in small-scale, non-industrial fisheries. It is difficult to imagine long configurations of deep-water offshore pots fished in heavy currents, incorporating weak portions of gear into buoy and groundline ropes. In these fisheries, other techniques such as acoustically released bottom-stowed vertical lines may be more appropriate.

b. Whale-release rope

An analysis of ropes retrieved from entangled whales off eastern North America found that whales of larger body size tended to be entangled in ropes of higher breaking strength and concluded that whales are more likely to break free from ropes with breaking strengths of 1700lbf or less (Knowlton et al., 2016). This finding encourages pursuing techniques that make vertical lines weaker than ones currently used which have a breaking strength of 2500lbf or higher, at least where they can be fished practically. In contrast to the weak links, this study indicates that more whale entanglements might be avoided because the weak portions of the rope are not concentrated only at the weak link below the buoy, but distributed along its length.

Over time, fishermen have transitioned from using natural fiber ropes to plastic ones with higher breaking strengths (Knowlton et al., 2016), and this might help explain why entanglements of North Atlantic right whales are increasing in severity despite many years of mandated modifications to fishing practices (Pace et al., 2014). The recent study by Knowlton et al. (2016), as well as broad interest in experimenting with reduced breaking strength ropes by fishermen in Massachusetts, suggest this relatively low-cost technique would reduce the incidence and severity of whale entanglements in areas where it can be fished safely and practically.

Between 2006-2008, the Bycatch Consortium produced ropes of 5/16” and 3/8” diameter, with 600 and 1200lb breaking strengths, respectively. The ropes were a mix of barium sulfate (60% by weight) and polypropylene (40% by weight). In many areas of inshore (shallow water) coastal Maine where fishermen deployed these ropes, they reported that the ropes fished satisfactorily. However, some fishermen expressed concerns —particularly in rocky-bottom sea floor habitats—that the ropes were more prone to abrasion and severing.

Two recent series of measurements on lobster pot gear in the Gulf of Maine carried out independently by the Anderson Cabot Center for Marine Life (ACCOL) and Maine’s Department of Marine Resources recorded loads well below 1700lbf in waters of 137m or less, and only exceeding that threshold when different gear sets were laid atop one another and the lower one hauled (“hang-up”). These results indicate that from a fishery perspective these ropes may be fished practically at least under some circumstances. The loads were consistent with what a computer model found on lobster pot gear configurations, in which hauling a 20-pot trawl at a velocity of 3kts would be required to reach a load if 1700lbf (Decew 2017).

c. Other devices

Several methods are currently in use or proposed for use to weaken portions of pot line to help passively free an entangled whale. On identified in the *2015 Gear Research Needs and the Atlantic Large Whale Take Reduction Plan* refers to a “zap link” incorporated into the lobster trap groundline to release a whale if a force of 200lbs were exerted on it (http://www.greateratlantic.fisheries.noaa.gov/protected/whaletrp/research/index.html). NMFS abandoned consideration of this idea once the sinking groundlines were required in the lobster fishery.

Other weak link ideas include splicing pieces of manila into the plastic polymer ropes used by the industry (Smolowitz and Wiley, 1998), breakaway buoys (Smolowitz and Wiley, 1999), and cutting buoy lines into sections and then re-assembling them into a continuous line by inserting the ends into a braided sleeve that holds them together. Additional devices or techniques under this category include the following:

<u>Buoy line messenger system</u> – A device that transports a haul line down a buoy line of low breaking strength rope (“tag line”) for hauling (Smolowitz and Wiley, 1999). Alternatively, the haul line could be stored at the trap, and pulled to the surface when a “messenger” (such as a cleat) is run down the tag line and attached to it.

Trials of the buoy line messenger system produced encouraging results, although one major concern is the cost and practicality of using double the amount of vertical line (tag and haul line) (Smolowitz and Wiley, 1999), as well as the additional hauling time involved. If these issues were manageable by pot and gillnet fishermen, it is a technique worth investigating.

<u>Thwartable bottom link</u> – A tubular attachment through which the deepest part of a submerged vertical line is inserted and could be severed by a blade using a timed or on-demand mechanism (Schrock and Schrock, 2011). According to the patent description, during gear deployment, the device secures and prevents the rope from moving toward the blade unless a force is exerted on the vertical line by an entangled whale.

<u>Knots</u> – Knotting reduces the breaking strength of the line at the location of the knot.

Similar devices have been proposed, and may be found through an online search of patents.

Most of these devices operate by severing buoy lines. In areas where whale encounters are frequent, this could result in gear conflicts if fishermen no longer see surface buoys identifying where gear has been set. For the most part, however, entanglement events are relatively rare, so if cutting devices functioned soon after the encounter, whales may not carry off gear, making it more likely that fishermen can retrieve gear where the buoy was no longer present.

Longline weak hooks

Weak hooks involve decreasing the bending strength of the hook to a point where it straightens and facilitates release when pulled by a marine mammal, while remaining strong enough to retain target catch (Bayse and Kerstetter, 2010; Bigelow et al., 2012). This method is mainly applicable in pelagic longlines. Target species catch could be affected if the terminal tackle is not optimal for retaining it. Where no other deterrence is possible, it may be the only solution for minimizing bycatch of small odontocetes. It is highly practical because it involves minimal change to current practices, and does not require knowledge of how the animals cue into gear or fishing operations. This technique can reduce bycatch but not depredation. An important research priority should be on understanding the severity of injury to animals that have been hooked, and those that escape from weak hooks (see McLellan et al., 2015). Post-hooking mortality is poorly known.

Camouflage

Concept: Marine mammal depredation on target catch can be reduced if it is difficult to detect visually or acoustically by echolocating cetaceans

Relevant fishing gear: Longlines (demersal)

Target marine mammals: Odontocete cetaceans

Summary from evidence: To date, acoustic screens have not shown promise experimentally.

Safety/operational considerations: Use of this technique requires only minimal additional labor to attach acoustic camouflage-producing units.

Economic concerns: This is a relatively low-cost gear modification.

Description: This technique would use bubble screens or attaching components such as acrylic beads to simulate the acoustic signal of target catch to confuse a marine mammal from detecting the actual catch (Straley et al., 2013; O'Connell et al., 2015). Moreno et al. (2008) used "pulpo", knots in the terminal hook lines of a demersal Chilean longline to hide the presence of fish from depredating sperm whales. Unfortunately, this technique failed to maintain the camouflage effect when currents or boat movement caused the knots to "flap." This is an inexpensive tool, but many similar passive reflective devices experiments have shown they do not work. Nevertheless, previous work has shown that whales 'see' when echolocating on target fish, and they do avoid acoustic profiles of snarls and rockfish, so this technique cannot be entirely ruled out.

Catch protecting gear

Concept: Surrounding target catch before and during hauling on longline gear will prevent or deter marine mammals from removing hooked catch or partially consuming it.

Relevant fishing gear: Longlines

Target marine mammals: Odontocete cetaceans, pinnipeds

Summary from evidence: Depredation rates by toothed cetaceans, pinnipeds, and seabirds are reduced in some trials using catch-protecting devices without affecting target catch. However, in some studies, attributing fish removal or bite damage to sharks versus marine mammals confounds the results reported. Published studies suggest additional work is needed to reduce the failure rate of devices, and to determine if habituation is an issue.

Safety/operational considerations: Units can sometimes fail to release components that encapsulate target catch or become tangled. Deployment takes additional time than typical gear used.

Economic concerns: Gear cost increases depending on the type of devices used. In some cases, these costs may be recaptured by increasing retained catch (catch that is neither removed nor partially eaten through depredation).

Description: Any triggered device that encapsulates target catch, such as dangling chains or plastic filaments, to deter depredation (Moreno et al., 2008; Hamer et al., 2012; 2015; Rabearisoa et al., 2012; 2015). Moreno et al. (2008) reported reduced depredation rates by sperm whales and South American sea lion (*Otaria byronia*) on demersal longlines using a conical net that encapsulates the target catch during hauling, and over time fewer observations of sperm whales in the same vicinity of longline fishing. Nevertheless, it is unclear how the depredation rates compared between the baseline rate and use of the conical net, since the authors noted that sharks also depredate the target catch. Hamer et al. (2015) report some reduction in target catch depredation using a plastic canister that released chains when the force of a caught fish tugged on the hook line. The differences were not always statistically significant because shark depredation also occurred with the longlines and some devices failed to function properly. These studies also noted higher target species catch rates and suggested this may be due either to reduced depredation or the units attracting more fish to the baited hooks.

Goetz et al. (2011) tested a similar device in a southwest Atlantic pelagic longline fishery targeting Patagonian toothfish, depredated by sperm whales. Depredation comparisons were difficult due to small sample sizes; however, lower fish catches when using the catch protecting gear did not encourage the use of the design tested in this fishery. A trial involving pelagic longline interactions with bottlenose and spinner dolphins using streamer lines made of tarpaulin and connected to a PVC tube that surround the baited hook (“DEPRED”), showed some reduction in depredation damage by each species in some trials carried out off Réunion (Rabearisoa 2015). Another trial reported in this paper used a “spider” consisting of polyester lines extending over the hook from an attachment to a circular disk, and a net bag in a pelagic longline fishery off the Seychelles (Rabearisoa 2012). Target catch was swordfish and tuna, and the depredating species were false killer whales, short-finned pilot whales, and sharks. Sample sizes were insufficient to determine if the devices reduced depredation rates when compared with control hooks, and there was some device failure. Fishermen participating in the study reported some operational difficulties in using the devices. A sturdier and totally encapsulating catch pod was developed by a Norwegian company for demersal trawls (Arangio 2012). During hauling, the longline passes through the device and the catch is removed from the hook and retained within a cylindrical case resembling a small submarine. Hook avoidance by bottlenose dolphins was observed in a king mackerel troll fishery off Florida, US, with no difference in target catch (Zollett and Read, 2006).

Catch protecting gear may be more effective in deep water demersal fisheries because fish only need to be protected during hauling (not soaking). Continued and persistent use of these devices could break the reward cycle to suppress depredation. The feasibility of using these in pelagic fisheries is probably less because of an anticipated increase in labor, crew, and cost, but operational concerns may be overcome with additional research (see Hamer et al., 2015).

The use of these devices can increase the weight of branch lines or snoods, which can get baited hooks quicker off the ocean surface where depredation rates by seabirds are highest and cause lethal interactions (Moreno et al., 2008).

Decreasing gillnet mesh size

Concept: The entanglement property of a gillnet with marine mammals will be reduced by decreasing its mesh size

Relevant fishing gear: Gillnets

Target marine mammals: Cetaceans

Summary from evidence: Insufficient evidence exists to support the use of this technique for reducing marine mammal bycatch. It is difficult to imagine adopting a mesh size that might reduce marine mammal bycatch in favor of one that optimizes the desired size class of target catch.

Safety/operational considerations: None.

Economic concerns: Using a smaller mesh size likely trades marine mammal bycatch reduction benefits (if any), with catching the desired target catch size, possibly leading to lower revenues.

Decreasing the gillnet mesh size may reduce the small cetacean entanglement while maintaining adequate catch. In Mexico's Gulf of California, a regulatory measure banned gillnets with a mesh size greater than 10-inches to reduce vaquita bycatch, however it has been reported that vaquita are caught in gillnets of much smaller mesh sizes (Rojas-Bracho et al., 2006). Later, gillnets with mesh sizes greater than 6-7.8 inches were also banned as part of the Vaquita Refuge Program, which Rojas-Bracho and Reeves (2013) reported as potentially reducing vaquita bycatch by as much as seven individuals/year.

In Germany's Small Cetacean Sanctuary West of the Islands of Sylt and Amrum, gillnet fishing is permitted with nets with mesh sizes less than 150mm, or roughly the same size as the 6in mesh in Mexico (Proelss et al., 2011). Scientists report that this measure in combination with restrictions limiting the gillnet height to 130cm, should prevent harbor porpoise bycatch. The authors do not report data on comparative bycatch to support this conclusion, however.

A literature review of factors affecting bycatch rates for marine mammals, sea turtles, and sea birds, identified mesh size as one of the factors correlated with bycatch rates (Northridge et al., 2017). Nevertheless, the review did not probe further into the magnitude of mesh size, and the authors emphasized that target catch selectivity is an overriding concern in selecting the mesh size used in a given fishery.

Decreased soak time

Concept: Reducing the time that gear is in the water lowers its exposure to marine mammals, which can result in less bycatch.

Relevant fishing gear: Gillnets, pots, longlines

Target marine mammals: Cetaceans

Summary from evidence: Few studies exist to support this conclusion; however, it is an advisable practice even though alone it is unlikely achieve bycatch reduction targets.

Safety/operational considerations: Many fishermen tend to keep gear in the water only for as long as needed to obtain adequate target catch. However, fishermen may leave gear set in an area even when not actively fishing to prevent others from fishing there or for other reasons.

Economic concerns: No change from current practices would be required unless additional trips from port are necessary, which would increase fuel costs and other operating expenses.

Description: Keeping fishing gear in the water only for as long as needed to yield a sufficient catch should decrease the risk that it will entangle or catch a marine mammal. The U.S. regulations under the Atlantic Large Whale Take Reduction Plan [https://www.greateratlantic.fisheries.noaa.gov/Protected/whaletrp/] mandate that no gear can be left, avoiding wet storage, which reduces the amount of time gear would be deployed.

Northridge et al. (2017) suggested that reduced soak time should lower bycatch risk however it might also reduce target catch per haul. A study that compared Maine lobster fishing effort with that of the adjacent lobster fishing zone in Canada concluded that reducing the fishing effort in the former from one year to six months as well as reducing the number of traps by a factor of ten could produce the same lobster catch while reducing the risk of entangling right whales (Myers et al., 2007).

Decoys (physical and acoustic)

Concept: Creating physical or acoustic imitations of longline operations will attract cetaceans that depredate target catch away from the actual longline deployments.

Relevant fishing gear: Longlines

Target marine mammals: Odontocete cetaceans

Summary from evidence: Limited evidence to support that this technique is effective.

Safety/operational considerations: Physical dummy sets require more gear and time on the water, which may be a disincentive to using them.

Economic concerns: Higher costs from more labor and more gear would have to be offset by increased revenue from landing fish that would otherwise be lost to depredation.

Description: One type of decoy is an incomplete longline set (e.g., lacking hooks) that mimics an actual fishing set to trick marine mammals into interacting with the decoy rather than actual set, and over the long-term decrease their motivation to seek out the latter (Thode et al., 2012). This technique would incur significant increases to fishing expenses and labor with questionable benefits but could be easily tested experimentally. Another approach used playbacks of the sounds produced during longline hauling to lure sperm whales from depredating on black cod in southeast Alaska (Thode et al., 2012). A dummy set equipped with a playback device showed that sperm whales remained away from the actual set for a longer time.

Whales seem to home in on vessel noises, so quieting vessels could be effective. Understanding the extent to which marine mammals use cues for finding vessels would be required to evaluate the potential of this technique.

Dolphin gate/weighted cork line

Concept: Assuming purse seiners intentionally or accidentally set on dolphins while targeting sardines, they can avoid capture using an escape way maintained below the ocean surface by a weighted line at one end of the net

Relevant fishing gear: Purse seine net

Target marine mammals: Odontocetes

Summary from evidence: They do not appear to be effective and have been abandoned as a technique in an Australian sardine fishery

Safety/operational considerations: Does not avoid the need for crew intervention to assist dolphins escape which is risky

Economic concerns: Adds additional labor time and gear expense.

Description: These measures were developed in tandem with others to form part of a code of practice for sardine purse seiners in Australia. The dolphin gate is a removable section of the corkline that crew can unlatch to facilitate the escape of dolphins (Hamer et al., 2008). Weights are carried on board the seiner to help sink the cork line. The technique is no longer part of the code of practice because it does not appear to function as intended (Hamer et al., 2008) and are unsafe for crew (Ward et al., 2015).

Electric barriers

Concept: Partially or fully electrified gear would create an aversion response in pinnipeds so they stopped depredating on fishes caught in gillnets.

Relevant fishing gear: Gillnets, aquaculture

Target marine mammals: Pinnipeds

Summary from evidence: Only one study from a freshwater environment exists, where the authors reported higher target catch and lower depredation in an electrified portion of a gillnet.

Safety/operational considerations: Using electricity in fishing introduces a safety risk, and the gear must be maintained especially as it is needed to operate in a wet environment.

Economic concerns: The added expense of electrifying gear should be offset by increased revenues from higher catches that would otherwise be lost to depredation.

Description: Forrest et al. (2009) tested the effects on target catch (pink salmon (*Onchorhynchus gorbuscha*) and sockeye salmon (*Onchorhynchus nerka*) from Pacific harbor seal (*Phoca vitulina richardsi*) depredation in a gillnet with a low electric current running through its upper portion. Tested in mostly freshwater, the study recorded higher salmon catch in the electrified side of the net and less evidence of depredation from the non-electrified side. The authors identified a need for additional trials comparing fully electrified and non-electrified nets rather than one that had both characteristics. If given a preference, a seal may favor preying on salmon from the non-electrified side of the net. However, if only an electrified net were available, it remains to be evaluated if opportunistic feeding would still be deterred.

The use of electromagnetic deterrents for deterring fisheries interactions with non-target elasmobranchs has been a very active area of research with highly variable results (see reviews by Jordan et al. (2013) and Porsmuguer et al. (2015)).

Excluder devices

Concept: Trawls can reduce marine mammal bycatch by having escape routes built into them should an animal be unable to swim clear of the trawl opening.

Relevant fishing gear: Trawls

Target marine mammals: Small cetaceans, pinnipeds

Summary from evidence: Several studies show that bycatch of marine mammals can be reduced by using trawls equipped with excluder devices; however, the results are variable depending on the exclude device design. In addition, survivability after passing through the escape panel must be taken into account or the devices may not have their intended effect.

Safety/operational considerations: Tilzey et al. (2006) reported that most seal foraging occurs when the nets were being hauled back. For fisheries where the target species is larger than squid or other forage fish, such as blue grenadier, which can grow to be 1 m long, excluder device design is particularly important. If not designed correctly, excluder devices can lead to loss of catches and mammals, particularly seals, entering the net through the escape hatch (Tilzey et al., 2006).

Economic concerns: Excluder devices are used in many fisheries worldwide, apparently having been incorporated into fishing activity without affecting fisheries profitability.

Description: Excluder devices usually consist of a grid, through which the target catch can pass but a marine mammal or something of a similar size cannot. The grid is placed inside the net, before the codend, at an angle, so the mammal will slide towards an escape panel in the net and pass through it (Dotson et al., 2010; Baker et al., 2014). The escape panels are placed on the top or bottom of the net for mammals, and top placement has proven the most effective at allowing pinnipeds to escape trawl nets, perhaps because of their need to swim upwards for air (CCAMLR 2017; Hamilton and Baker, 2015a; Tilzey et al., 2006). Excluder devices can be used to avoid finfish, sea turtle, marine mammal, and sea bird bycatch.

Excluder devices can be effective at reducing marine mammal bycatch, particularly of pinnipeds, when designed correctly (Baker et al., 2014). Escape responses and other behaviors of marine mammal bycatch species must be known, as well as size and shape differences between target and bycatch animals. For each fishery, tow speed, depth, gear characteristics, vessel size and the space in which and way the gear is stowed must also be taken into account (Baker et al., 2014; Hamilton and Baker, *in review*). Because midwater trawls can be towed at higher speeds and often target species that are common prey for marine mammals, such as squid or small, schooling fish, these have higher potential for interacting with marine mammals than bottom trawls (Read 1994). Mammals can be caught in trawl nets while feeding, or they may learn to associate the gear with prey.

Several studies have reported that excluder devices were effective in reducing trawl net bycatch for common bottlenose dolphins *(Tursiops truncatus*) (Allen et al., 2014), New Zealand sea lions *(Phocarctos hookeri)* (Hamilton and Baker, 2015a), common dolphins *(Delphinus delphis)* (Northridge 2003), and New Zealand fur seals *(Arctocephalus forsteri)* (Stewardson and Cawthorn, 2004) with minimal effects on target catch; however, the fate of escaped animals has not been adequately tested and is a research priority. Evidence exists from many different trials that excluder devices have reduced New Zealand sea lion *(Phocarctos hookeri)* bycatch in the Auckland Islands squid fishery (Hamilton and Baker, 2015a; Hamilton and Baker, 2016). These authors report that sea lion excluder devices have been used by all vessels in that fishery since 2004/05 and since then, annual estimates of bycatch decreased from 31 to 4 in 2010/11. However, these reduced bycatch estimates may be misleading, as the population continued to decline (Meyer et al., 2017), although pup production has stabilized in recent years (Childerhouse et al, 2017). Hamilton and Baker (2015a) report that excluder devices have been found to reduce sea lion bycatch in trawl nets and that research has shown that fatal head trauma from contact with an exclusion device grid is unlikely and there is a high likelihood that sea lions survive their encounters with device grids. Tow and haul speeds made a difference in the number of Australian fur seals (*Arctocephalus pusillus doriferus*) caught in trawl nets in a 2006 study (Hamer and Goldsworthy, 2006). Due to low interaction rates during testing, this same study also found no evidence that escape through excluder devices was responsible for reduced seal bycatch, but that a reduction may have been due to a lower number of entries into the nets.

Video monitoring of seal excluder devices in trawl nets for the Australian midwater small pelagic fishery showed that most seals entered the net through the mouth and exited through the escape panel (Lyle et al., 2016). However, video monitoring showed dead seals falling out of the net equipped with a bottom-opening exit before it was hauled back. This could mean there may be unrecorded mortality of marine mammals in trawls equipped with bottom-opening excluder devices. Sometimes excluder devices can have a “hood” or “kite” attached to the escape panel of the net. This extra material can prevent loss of target catch and also of dead or injured marine mammal bycatch, so that it can be recorded. Hoods have been found to have a positive effect on escapes of pinnipeds (Baker et al., 2014). Increasing the size of the escape hatch (from 1m x 1m to 1m x 1.9 m) in the midwater small pelagic fishery reduced mortality rates by 21% (Lyle et al., 2016). Depending on the depth at which the gear was being fished, seals entered the nets during fishing time or only during setting and hauling back. If the net was towed at depths deeper than the seals’ diving depths, they entered during setting and hauling back, and if it was towed at diving depths, they mostly entered while the net was fishing.

A forward-facing hood is assumed to reduce catch losses and dead animals falling out. Robertson (2015) believed further testing is required (Robertson 2015; but see Hamilton ans Baker, 2015b). The addition of kite and floats on the hood ensures that the hood operates optimally (Hamilton and Baker 2015a; but see Robertson 2015; and subsequent response by Hamilton and Baker, 2015b). Exclusion devices, mandatory in relevant krill fisheries managed by CCAMLR have eliminated Antarctic fur seal bycatch (CCAMLR 2017).

Seal excluder devices enhance survival rates of seals by preventing entry into a net’s codend (Tilzey et al., 2006). However, it is difficult to verify performance and efficacy with low interaction rates between marine mammals and nets, and there are often a complex range of factors influencing interactions with net (Hamer and Goldsworthy 2006; Tilzey et al., 2006). Reduction in observed bycatch rates since the implementation of exclusion devices may be, in part, due to reduction in seals entering the net (Hamer and Goldsworthy, 2006). Significant target fish loss out the top-opening hole has been reported with a backward facing cover (Tilzey et al., 2006).

Video monitoring of marine mammal behavior in trawl nets shows that excluder devices are not as effective for cetaceans as with pinnipeds (Baker et al., 2014). Dolphins have been observed swimming out of the mouth of the net, and not head first through the escape hatch. In general, cetaceans are not as likely to enter the narrow opening to an escape panel as pinnipeds are. Individuals of at least 15 cetacean species worldwide have been found to feed in association with trawlers (Fertl and Leatherwood, 1997). Morizur et al. (1999) found that dolphins were mostly caught in trawl nets at night or close to dawn.

Further research is needed to redesign and test devices for reducing dolphin bycatch (e.g., the best location for devices in net; ensuring escape holes are obvious and easy to escape through, while retaining fish; better understanding dolphin behaviour in nets and factors that contribute to dolphin mortality (van Marlen, 2007)). In Australia's Pilbara demersal trawl fishery insufficient numbers of dolphins have interacted with nets to allow an assessment of device effectiveness. For example, in trials involving a top-opening hole, 2/7 bottlenose dolphins exited, and one dead dolphin was expelled when the net rotated 180° during the haul so that hole (with no cover) was orientated downward (Wakefield et al., 2014; Wakefield et al., 2016).

A soft/semi-flexible grid angled to a bottom-opening escape has been used in multi-species fisheries, with a decline in target catch (Sala et al., 2017; Stephenson and Wells 2006; Zeeberg et al., 2006) and an increase in dolphin bycatch rates despite their mandatory deployment (Allen et al., 2014). More research is needed on whether devices with a top-opening escape option would be effective in reducing cetacean mortality (de Haan 2014).

Among other design considerations, barriers located further forward in the net between large mesh and small mesh sections caused unacceptably high levels of gear drag and a large reduction in fish catch (Bord Iascaigh Mhara and University of St Andrews, 2010; Northridge et al., 2005; van Marlen, 2007). Proper binding is important to ensure that during operation the barriers do not inadvertently open.

Fence or net barriers

Concept: Create a spatial separation between marine mammals and fishing or aquaculture gear by deploying a net around the gear.

Relevant fishing gear: (Ring) seines, aquaculture

Target marine mammals: Cetaceans, pinnipeds

Summary from evidence: Encouraging reports from the use of these nets in salmon cage aquaculture

Safety/operational considerations: None identified

Economic concerns: Acquiring, using, maintaining, and replacing an additional net adds to aquaculture operation costs. Currently, no studies show that this additional expense was offset by higher revenues from reduced lost or damaged fish.

Description: The most common use of net barriers occurs in aquaculture farms as predator nets deployed outside the nets used to contain fish or longlines used for growing mussels. Iwama et al. (1997) summarize several studies that reported limited predation by pinnipeds in salmon aquaculture cages when an outer predator or barrier net is used. Prajith et al. (2014) described a net wall used by fishermen in India to deter dolphin interactions with ring seine nets but had no information from field trials and relied on responses to questionnaires administered to fishermen about whether this deterrent has been effective.

Grappling

Concept: Instead of hauling gear with buoy lines, pots could be retrieved by grappling for groundlines, used to attach strings of pots to one another, eliminating the risk of entanglement to large whales from buoy lines.

Relevant fishing gear: Pots

Target marine mammals: Mysticete cetaceans

Summary from evidence: Vertical lines used in pot gear are the primary source of entanglements to large whales, so their elimination would remove this bycatch risk. It is a less feasible option where pot fisheries use one pot per buoy line.

Safety/operational considerations: Grappling increases the time required to retrieve gear, and the absence of surface buoys can lead to an increase in gear conflicts in densely fished areas. Grappling sometimes is a preferred fishing method, as in a fishery for Golden crab off the southeastern U.S. Grappling can potentially result in more derelict gear because of the difficulty in relocating set gear and retrieving it.

Economic concerns: Less rope can reduce gear expenses, although more time on the water and the potential for more lost gear can increase costs.

Description: When groundlines connecting pots are used, grappling can replace the need for haul lines. Grappling involves deploying a large multi-pronged hook attached to a rope down to the seafloor, dragging it along the bottom to snare the groundline, and retrieving pots to the surface. Lobster pot fishermen operating off the eastern U.S. sometimes grapple for gear when hauling lines break or are otherwise unavailable.

Fishermen should be encouraged to experiment with and evaluate this technique under the assumption that—as is the case with bottom-stowed vertical lines and rope-less fishing—in densely fished areas it includes a method for identifying the presence of gear to other fishing and ocean-going vessels to avoid gear conflicts. In the absence of surface buoys, the potential for losing gear to conflicts with other fishermen is greater. An evaluation carried out in Maine of grappling for lobster trap trawls (two or more pots connected by groundline) reported a significant increase in the time necessary to retrieve gear, an average of 14.2 minutes vs. 1 for buoyed traps, a higher risk of injury, many more gear “set overs,” and difficulty in using the technique under high winds, currents, and wave heights (Pemaquid Fishermen’s Co-Op, 2012). Nonetheless, the trials were highly biased because they used only one lobster fisherman and using no comparison with different gear configurations. With the mandated use of sinking groundlines in much of this fishery, Maine lobster fishermen also report fewer successful recoveries of bottom traps using grappling (Ludwig et al., 2015), presumably because sinking groundline does not form a loop above the ocean floor to facilitate hooking.

The southeast US golden crab (*Chaceon fenneri*) fishery has a few fishermen who use grappling to retrieve traps because buoys cause the traps to drag along the sea floor.

This technique should be trialed in areas where strings of pots are used, where sea bottom topography is relatively flat, and where gear densities are low. In the absence of surface buoys, unless the presence of the gear can be identified to all fishermen operating within the area, it will be difficult to avoid gear being set on top of other sets, and gear inadvertently dragged to a different location will be difficult to locate and retrieve.

High tension gear

Concept: If nets or ropes were tauter, their entanglement properties would be reduced so that marine mammals would be less likely to become entangled, or have reduced access to prey on target catch or bait.

Relevant fishing gear: Pots, gillnets, trap-nets, aquaculture

Target marine mammals: Cetaceans, pinnipeds

Summary from evidence: Except for trap-nets, existing studies indicate this technique shows little promise as a bycatch reduction technique, and marine mammals become entangled regularly even in fisheries where they are used. In the case of gillnets, increased net tension may reduce target catch.

Safety/operational considerations: It would be difficult to maintain ropes under high tension during tidal cycles, and a reduction in rope length to create the tension required would make gear retrieval more difficult when tides submerge surface buoys. High rope tension can also lead to dangerous circumstances for fishermen when ropes part during hauling.

Economic concerns: In the case of gillnets, target catch may be reduced because the entanglement properties of ropes would be reduced. Trap-nets under higher tension can produce adequate target catch that shows less damage from pinniped predation than typical nets, however some designs are more expensive than others.

Description:

<u>Pots</u>
Line tension is achieved by increasing the counter forces of surface or subsurface flotation and bottom weight to create a taut line or net. The assumption is that high-tension lines make it harder for a whale to become entangled because they have reduced entangling property, possibly allowing the whale that encounters such a rope to "bounce" off before getting entangled. The concept is like that of rope stiffened materially even though in this case it is line tension rather than material stiffness. The degree of tension depends on the amount of weight and flotation used, the rope's tensile strength, and the influence of tides, currents, and winds. The surface end of ropes connecting buoys to bottom gear must be negatively buoyant in pot gear along much of the eastern U.S. because they are presumed to be tauter than float rope, reducing the amount of slack line in the water during low tidal and current flows (NOAA, 1997a). A similar idea considered by the ALWTRT was a "two buoy system" to reduce the scope of the line connecting the bottom gear to the first surface buoy. [See the *2015 Gear Research Needs and the Atlantic Large Whale Take Reduction Plan* gear matrix: http://www.greateratlantic.fisheries.noaa.gov/protected/whaletrp/research/index.html]. The logic behind the two-buoy system was to reduce the probability of ropes becoming lodged in the baleen of skim feeding whales, including right, sei, bowhead, minke, and gray whales, while surface feeding. A separate objective was to avoid conflicts with boat propellers on lines floating at the surface.

Too much weight or flotation attached to bottom gear can create impractical fishing conditions. Load cell measurements of lobster pot gear off the northeastern U.S. indicate current rope tension is relatively low except during hauling (Salvador et al., 2002). Also, changing tides, currents, and winds make it difficult to maintain a constant degree of tension in the line.

High tension vertical lines in lobster pot gear are created by using an anchor off the terminal lobster pots of a pot string in easternmost Maine. At least one record of an entanglement from this region has been documented, off Cutler (*Summary of NMFS Gear Analyses (1997-2007),* presented at the 2009 meeting of the Atlantic Large Whale Take Reduction Team). However, too few records indicating where whales are initially entangled in pot gear exist to conclude if this gear configuration poses more or less risk.

Stiffness properties of ropes and their effect on whale tissue was the topic of two lab studies. The first used an apparatus to create an oscillatory motion of ropes along the leading edge of a right whale fluke submerged in seawater (Woodward et al., 2006). The ropes tested were 3/8" (9.5mm) polypropylene float and polypropylene-polyester sink. Increasing rope tension was produced by using a 9kg weight, which produced a furrow 0.40 cm deep as opposed to a 0.27cm with 4.5kg. In both cases, the furrows caused by rope abrasion did not penetrate beyond the epidermis. Starting with the same apparatus, Winn et al. (2008) modified it to create a continuous loop of rope, to carry out an examination of tissue compliance. The ropes tested included 3/8in float and sink, as well as 1/4in float. This study compared the effect of rope diameter on specimens of a humpback fluke and well as a NARW fluke and flipper, exerting a maximum load of 31.8kg on the tissues. Epidermal failure was comparable between humpback fluke and both NARW flipper and fluke specimens despite their different epidermal thickness. However, the smaller diameter rope tested with the humpback fluke cut deeper into the epidermis than the thicker diameter line. These results suggest that high tension ropes may produce more severe injuries to whales along body parts where the entanglement creates a sawing motion. The latter experiment further demonstrated that a reduction in line diameter can produce worse lacerations at the same level of force exerted.

In another study examining the impact of lines on whale flippers, Baldwin et al. (2012) constructed a free-floating fiberglass NARW flipper model using measurements of outlines and bones from three different whale carcasses, and attached it to a re-fitted lobster boat. The flipper was driven into moored ropes under variable tension to examine whether higher tension ropes reduce entanglement risk. Simulations were run at the highest tide to increase line tension (425lb maximum), and involved three contact points along the leading edge of the flipper. Only at the outermost location did the rope slip free; at all other locations closest to the flipper attachment the line entangled. At these locations, and even at the outermost location, extreme sawing action frayed the outside leading edge of the flipper (22/30 events).

Considering the Woodward et al. (2006) and Baldwin et al. (2012) studies together argue against using ropes of higher tension because they result in more severe lacerations. However, the results relate to rope diameters (3/8in vs. 1/4in diameter ropes) with thinner ropes cutting deeper into whale tissue under higher loads (Winn et al., 2009). The presence of whale oil conceivably could promote greater slippage, but is likely not a critical factor. However, Cavorta et al. (2005) did show that polypropylene float ropes have lower friction against whale tissues than sink rope and other fibers tested.

Materially stiff rope

This technique involves increasing the bending resistance of a rope, also referred to as rope “hardness” or “firmness.” Ropes can vary in stiffness due to the materials used in their construction, changing the properties of the fibers, or from different manufacturing processes (e.g., tighter lay ropes, increased number of rope yarns/strand). In Western Australia, lobster pot ropes have a harder lay than those used in the eastern U.S., yet they still entangle southern right and humpback whales. Furthermore, stiff ropes have been retrieved from entangled whales, suggesting they are unlikely to be an effective bycatch prevention technique. If there is any bycatch reduction effect, it would likely be with smaller whale species that would exert less force that larger species to overcome the stiffness property of a rope and become entangled.

It is more difficult to splice stiffer ropes, so instead fishermen tend to knot them together. NOAA Fisheries discourages the use of knots because based on the assumption that they lead to entanglements. Injury severity from materially stiffened ropes might also be higher due to their increased ability to cut into whale tissue.

Materially stiffened ropes entangle whales, as evidenced by entanglement in fisheries where they are used and their removal from disentangled whales; furthermore, they may be more likely to cause more severe injuries than “softer” ropes. Their examination as a potential bycatch prevention technique is a low priority.

<u>Trap-nets</u>

Suuronen et al. (2006) compared various fish trap-net designs for catching salmon (*Salmo salar*) and whitefish (*Coregonus lavaretus*) in the northern Baltic Sea, and found the best design included adding an extra net layer and maintaining both layers under higher tension. The mesh consisted of strong *Dyneema* line, and in tandem these and other modifications reduced access to net contents by seals and the availability of fish entangled in netting.

<u>Gillnets: Changing the vertical tension</u>

Varying the counter force created by placing floats at the upper portion of a net and weights at the lower end can modify the vertical tension of gillnets. A paired trial using standard gillnets, and gillnets with twice the amount of lead and flotation showed no significant difference in the bycatch rates of harbor porpoise (SMRU 2008).

Thorpe and Frierson (2009) compared higher tensioned nets with standard gillnets in a North Carolina fishery and reported a reduction in the bycatch rates of some shark species with no significant differences in catch rates of target species. Increasing vertical tension beyond a certain threshold should reduce target catch rates in nets by reducing their entanglement properties and increasing their detectability by target fishes. Nets of increased stiffness would be more likely to reflect water movement back towards a fish approaching the net, enhancing its ability to sense the net from this return swell (Gabriel et al., 2005). Also, decreasing the entangling ability of gillnets by increasing the vertical "stiffness" may result in increased dropouts of bycaught marine mammals during hauling, leading to an underestimation of bycatch rates. Given the lack of any positive trials with marine mammals and the likelihood that some positive effect might only occur at tensions that would likely lower target catch rates, this approach does not seem a promising focus for further research for marine mammals.

Gillnets: Changing the horizontal tension (hanging ratio)
Hanging ratio relates to how the net is fastened to the head rope, with lower ratios indicating more slack in the net. The effect of hanging ratio on harbor porpoise bycatch rates was investigated in a trial of a 12 in-mesh monofilament gillnet fishery in New England, U.S. comparing nets rigged with a hanging ratio of 0.33 and 0.5 (Schnaittacher, 2010). There was no significant difference in the bycatch rates of small cetaceans (harbor porpoise and common dolphins) or pinnipeds (harp and grey seals) between the two nets, and the nets with the lower hanging ratio generally caught more finfish; although no statistical analysis was reported to indicate whether the differences were significant. As in the case of increasing vertical tension, these results do not indicate much promise in this approach for marine mammals.

Another concept for reducing marine mammal bycatch involves increasing net stiffness to reduce the entanglement properties of gill and entangling nets. While Larsen et al. (2007) found no difference in the acoustic target strength of iron oxide (IO) nets, the stiffness of the nylon as measured using E-alpha, the modulus of elasticity (IUPAC 1997), was found to be three and one-half times greater than the standard nylon net. The increased stiffness of the IO nets could explain the observed reduction in harbor porpoise bycatch during this trial. Increasing the stiffness of the nylon also reduced target catch, which is not surprising given that softer net materials tend to produce higher fish catches (Gabriel et al., 2005).

Mooney et al. (2007) also found that the $BaSO_4$ gillnet filaments used by Trippel et al. (2003) were significantly stiffer than the nylon used in standard gillnets. However, the stiffness of net filaments used in the most recent trial of $BaSO_4$ nets were found to be lower than those used in standard nets (Bordino et al., 2013). This finding was consistent for samples tested when dry or saturated in seawater. The authors concluded that the difference from Mooney et al. (2007) might be explained if different grades of nylon were used in the two studies comparing flexural stiffness. In the 2013 study, both standard and experimental twines originated from the same manufacturer using the same grade of nylon, whereas in the previous study the twines were acquired from different sources. Bordino et al. (2013) also investigated bycatch rates of Franciscana dolphins in nets that were 19.4% stiffer in seawater by using a higher quality nylon to increase the flexural stiffness of the mesh webbing and found no significant reduction in bycatch rates compared to standard nets. No measures of stiffness were recorded in trials using $BaSO_4$ nets by Northridge et al. (2003).

Another way to increase the stiffness of the mesh webbing is by increasing the diameter of the nylon filaments. Under the U.S. Harbor Porpoise Take Reduction Plan (NOAA 2010), a minimum twine size of 0.9mm is required in Mid-Atlantic large mesh gillnet fisheries (7–18 inches) after preliminary analysis showed higher bycatch rates in large mesh fisheries using thinner twines (M. Rossman, *pers. comm.*). In addition, a minimum twine size of 0.81mm is required in Mid-Atlantic small mesh gillnet fisheries (>5 to <7 inches). Thin twine monofilament nets (0.4 mm twine diameter, 90 mm mesh size) reduced bycatch of harbor porpoise and seals in the North Sea and West of Scotland gillnet fisheries when compared to thick (0.6 mm twine diameter, 267 mm mesh size) monofilament nets (Northridge et al., 2003). However, nets of variable mesh size were used in this trial so quantifying the degree that twine versus mesh size contributed to bycatch reduction would be necessary to see if twine size was an explanatory variable in the differences recorded.

It remains unclear if some increase in the material stiffness of gillnets may reduce bycatch of harbor porpoise while still maintaining catch rates of target species, although from a fisheries perspective increasing stiffness generally should result in reduced target catch.

<u>Aquaculture nets</u>
Anecdotally, increasing the net stiffness in salmon aquaculture pens decreases depredation rates of pinnipeds, presumably because it is more difficult for them to manipulate net shape in ways that facilitate access to caged fish (Iwama et al., 1997).

Increase hauling speed

Concept: An increase in hauling speed might reduce the probability that depredating cetaceans can remove target catch.

Relevant fishing gear: Longlines, trawls

Target marine mammals: Odontocete cetaceans

Summary from evidence: Not tested.

Safety/operational considerations: Unknown, however increased hauling speed also increases the load on haul lines. Increasing hauling speeds may be operationally infeasible.

Economic concerns: More fish might be lost by falling off hooks when haul speed is increased.

Description: It has been suggested that in longline gear increasing hauling speed might reduce the probability that marine mammals can take target catch by "outrunning" them (*see* Tixier et al., 2015). This technique may be more applicable to demersal longlining where fish are depredated during haulback.

For trawls, the benefits of implementing rapid hauling and deployment of gear are unknown as elements of various codes of practice for the Australia blue grenadier (*Macruronus novaezelandiae*) fishery (Tilzey et al., 2006), New Zealand deepwater trawl fisheries (Deepwater Group 2017), and with the Southeast Trawl Fishing Industry Association (SETFIA 2007). This technique has not been examined individually and is part of multiple measures under the CoP (see *Special Measures*).

Lethal removal/physical harassment

Concept: Killing, hurting, or non-acoustic harassment of marine mammals that remove or damage target catch or farm-raised species increase the revenues from fishing and aquaculture.

Relevant fishing gear: Longlines, aquaculture, other?

Target marine mammals: Mainly pinnipeds and odontocete cetaceans

Summary from evidence: This is a common practice in several countries, but its effectiveness and impact on marine mammals remains largely unquantified.

Safety/operational considerations: None identified

Economic concerns: None, although reduced interactions might increase target catch or undamaged farm-raised species and the pens in which they are contained.

Description: This technique involves exclusion of depredating marine mammals by using firearms, explosive devices or other non-acoustic harassment methods (Dalheim, 1988). Included here is vessel chasing, in which longline vessels pursue depredating marine mammals to scare them away from fishing operations. Anecdotal reports and permitted activities where fishermen and aquaculture operators kill marine mammals that depredate their farmed or wild caught target species are common. In Scotland, there is an allowable annual quota on the number of grey and common seals that aquaculture farms may remove by lethal means (Part 6 of the Marine (Scotland) Act 2010). The numbers reported as "removed" number fewer than those allowed under the quota; however, it is uncertain whether the rate is sustainable for all populations. There are no reports on the effectiveness of using this technique and whether it has reduced pinniped interactions with salmon farms over time. Provided the numbers taken are accurately accounted and do not threaten the persistence or recovery of the target marine mammal populations, this technique may be useful, although the issue of animal welfare may be a concern to many in the general public and nations that have outlawed the practice.

Lipid soluble rope

Concept: Using a rope that dissolves upon contact with whale blubber can free more entangled whales.

Relevant fishing gear: Pots

Target marine mammals: Large whales

Summary from evidence: The product has never been developed, and even if feasible would not reduce injury severity which impacts health and survivability.

Safety/operational considerations: If such a rope were developed, it might not be fishable.

Economic concerns: Unknown, but likely would increase gear expenses.

Description: Members of the U.S. Atlantic Large Whale Take Reduction Team considered the idea of a rope that would dissolve when encountering whale blubber allowing it to eventually fall off the animal. No such prototype currently exists, and for such a rope to function it would need to cut into the blubber layer of a whale before it begins to dissolve. This means the rope would have to seriously lacerate the whale, making it prone to infection and other adverse health impacts that have a high risk of lethal consequences. This technique is contrary to the objective for all fishing gear modifications to prevent whale entanglements or at least facilitate release *almost immediately* following a collision with rope and reduce the risk of serious injury.

Metal oxide/barium sulfate nets

Concept: If cetaceans could detect gillnets using echolocation, they might be more likely to avoid them.

Relevant fishing gear: Gillnets

Target marine mammals: Echolocating cetaceans

Summary from evidence: Some studies reported reductions in small cetacean bycatch; however, this is likely due to the reduced net area created by how these nets suspend in the water column. Even if they were to function as intended, their detection would not be possible when cetaceans are not echolocating.

Safety/operational considerations: None.

Economic concerns: Several studies indicate that target catches are reduced when using these nets, a conclusion possibly consistent with the reduced net area within the water column compared to standard nets.

Description: Dawson (1994) reviewed several studies in which acoustic target strength of gillnets was increased to reduce bycatch of echolocating cetaceans. These methods included adding reflectors to nets and using air-filled nylon strands and bead chains. However, very few of the studies reviewed were part of paired experimental trials, and few had sufficient statistical power to detect differences in bycatch rates between standard and modified gillnets. Dawson concluded that no study up to 1994 demonstrated that such modifications achieved "unequivocal, large reductions in catch rate(s) of cetaceans."

In the late 1990s, Trippel et al. (2003) tested a modified bottom-set gillnet where the acoustic reflectivity of its nylon filaments was increased by adding barium sulphate particles ($BaSO_4$, 10% by weight). The assumption being that the addition of barium sulphate to the net would increase its detectability by echolocating cetaceans. The results showed a significant decrease in harbor porpoise bycatch rates in the modified net (Trippel et al., 2003). Larsen et al. (2007) also found a significant decrease in harbor porpoise bycatch rates and catch-per-unit effort (CPUE) of cod (*Gadus morhua*) in a net made more reflective by adding iron oxide (IO). In contrast, a trial of standard and $BaSO_4$ nets by Northridge et al. (2003) found no reduction in harbor porpoise bycatch in modified nets. However, the mesh size and rigged height of the control and experimental nets used in this last trial were different, making it difficult to determine which factors most contributed to the observed bycatch rates. Trippel et al. (2008) reanalyzed data from their first trial together with additional data collected in subsequent years and again reported a reduction in harbor porpoise bycatch in $BaSO_4$ nets compared to control nets. This second analysis showed a significant reduction of haddock (*Melanogrammus aeglefinus*) catches in the modified nets, but no significant difference in catch rates of Atlantic cod, pollock (*Pollachius virens*) or spiny dogfish (*Squalus acanthias*).

The acoustic properties of these "reflective" nets have been tested in field and laboratory trials (Trippel et al., 2003; Mooney et al., 2004; Koschinski et al., 2006; Larsen et al., 2007; Mooney et al., 2007). Trippel et al. (2003) found that $BaSO_4$ gillnets were approximately three times more reflective than standard nets when ensonified with a 200 kHz multibeam sonar. Mooney et al. (2004, 2007), using generated broadband dolphin-like clicks and narrowband porpoise-like clicks, reported that the target strength of both $BaSO_4$ and IO nets was greater than comparable nylon nets at, or near, perpendicular angles. However, the returned levels of echolocation click signals were the same for both reflective and unmodified nets when the angle of incidence was greater than 40 degrees. Mooney et al. (2007) also found that although IO nets had a higher density than barium sulphate nets, they had lower relative target strengths. In contrast, a separate study using sound pulses of 200 µs at 140 kHz at a distance of 2m from an IO and standard net found no significant difference in target strength between the two net types (Larsen et al., 2007). In addition, a field trial that utilized porpoise click detectors (TPODs) to examine the echolocation behaviour of wild harbor porpoise around reflective nets found no difference in echolocation rate or echolocation intensity compared to control nets (Cox and Read, 2004).

Bordino et al. (2009, 2013, *unpublished data*) found no significant reduction in the bycatch of Franciscana dolphins (*Pontoporia blainvillei)* in $BaSO_4$ nets (5% by weight in the 2009 trial, and 10% in 2013). Underwater depth sensors were deployed on actively fished nets during the second trial and showed that $BaSO_4$ nets fished with a significantly lower float line height than standard gillnets. This may account for the decrease in harbour porpoise catch observed by Trippel et al. (2003, 2008) and haddock catch in the later study using $BaSO_4$ nets that lacked any additional flotation to compensate for the increased specific gravity of the nets. As a result, these nets may be fishing with a lower profile than the standard gillnets used in their trials. The finding by Cox and Read (2004) of no significant increase in the echolocation rate of harbour porpoise around acoustically reflective nets, and the observation that barium sulphate nets can have a lower profile, support the hypothesis that the reduction in harbour porpoise bycatch rates reported by Larsen et al. (2007) and Trippel et al. (2003, 2008) was a result of either the increased stiffness of these nets (Larsen et al., 2007) or the reduced fishing height of $BaSO_4$ nets.

Considering the results of these studies together, there is an important observation related to the manufacture and performance of experimental nets. We acquired used and new monofilament samples supplied by researchers who carried out the barium sulphate net trials and analyzed the amount of the compound they contained by weight. Three separate monofilament samples from each net were independently analyzed for barium content, which was used to calculate the percent concentration of barium sulphate. Based on these analyses, manufacturers were not consistent in meeting the 10% concentration target. Earlier trials by Northridge et al. (2003) and Bordino (2009, *unpublished data*) used nets with much lower concentrations of barium sulphate (*Table 2*). For one study (Bordino et al., 2013), barium sulfate content was analyzed for unfished and fished monofilament samples and noted the concentration did not change remarkably following submersion in sea water and exposure to the sun, so the compositions analyzed for all studies should be comparable.

Trippel et al. (2003) found a reduction in seabird bycatch (greater shearwaters (*Puffinus gravis*)) in $BaSO_4$ nets and postulated that this was due to the increased visibility of these nets, as the addition of this compound renders the net material opaque. This result is consistent with studies of diving birds in the U.S. Pacific Northwest when the upper portion of gillnets used opaque mesh (Melvin and Conquest, 1996; Melvin et al., 1999). Another possible explanation is that barium sulfate nets lay at a slightly greater depth so that potential contact points with diving birds would be reduced.

Table 2. Analysis of percentage (by weight) of barium sulphate contained in experimental nets. All studies commissioned manufacturers to produce nets that contained 10% $BaSO_4$. The nets tested were of fished samples except where noted ("new"). Three monofilament samples were tested from each net. (Source: Consortium for Wildlife Bycatch Reduction)

Trial	**% $BaSO_4$**	**Average**
Trippel et al., 2003, 2008	11.09	
	9.41	
	9.80	10.10
Northridge et al., 2003	7.74	
	8.22	
	7.40	7.79
Bordino et al., 2009	4.60	
	4.69	
	4.60	4.63
Bordino et al., 2013 (new)	9.81	
	9.63	
	9.88	9.77
Bordino et al., 2013	9.19	
	10.14	
	9.35	9.56

Current evidence suggests that the decreases in harbour porpoise (and perhaps seabird) bycatch rates in $BaSO_4$ nets and IO nets reported in some studies resulted from the mechanical properties of these nets and not any increase in acoustic reflectivity. Given the current body of work, there is little merit in continuing to examine the potential of increasing the acoustic target strength of gillnets to reducing small cetacean bycatch. Additionally, even if such modifications were effective, it would apply only to echolocating cetaceans—and only if they were echolocating in the presence of nets.

Minimize ratio of vertical lines to units of gear

Concept: In pot fisheries that use groundlines to attach strings of pots, having fewer buoy lines per pot strings reduces the number of vertical lines in the water, likely reducing the probability of large whale entanglements.

Relevant fishing gear: Pots

Target marine mammals: Mysticete whales

Summary from evidence: One modeling study suggested a reduction in but not elimination of entanglement risk. Any risk reduction must be quantifiable to ensure the persistence or recovery of the marine mammal population of concern. “Trawling up” in the U.S. prompted some fishermen to increase their vertical line diameter, resulting in higher breaking strengths which increase entanglement risk and the and severity of entanglements to large whales.

Safety/operational considerations: Increasing the weight of pots to be hauled can lead to more frequent haul line partings and therefore more derelict gear.

Economic concerns: Trawling up may reduce the length of vertical line that a fisherman needs to purchase but may also cause them to purchase more expensive, larger diameter ropes. Derelict gear that might result from this practice can cause lost revenue from lost target catch and gear.

Description: In the U.S., NOAA Fisheries mandated that in some pot fishing areas, fishermen “trawl up” to maintain fishing effort but reduce the number of vertical lines. Trawling up reduces the ratio of endlines to bottom gear, to maintain the same fishing effort but with fewer vertical lines in the water.

One study (Kite-Powell et al, *unpublished*) showed encounter probabilities in the northeastern U.S. would be reduced. However, whales still become entangled, and the bycatch reduction from a vertical line reduction is uncertain, including whether it reduces entanglements to a level that avoids extinction and promotes recovery. Because of this regulation, some lobster pot fishermen report they have increased the diameter of buoy line they use, which would likely decrease the probability that whales would break free of gear. This technique is only applicable where pot fishermen use multiple pots connected by a groundline. Increasing the number of pots/string will increase groundline length, and groundlines are another source of whale entanglements. The assumption in US fisheries, however, is that sinking groundlines do not pose a risk to whales.

Move-on Rule

Concept: Interactions or marine mammal mortality or injury would be kept manageable by only allowing them to occur up to a certain quantified threshold.

Relevant fishing gear: All

Target marine mammals: Odontocete cetaceans

Summary from evidence: This technique has not been evaluated in longline fisheries and is not practical or effective as a bycatch mitigation technique in U.S. pot and gillnet fisheries that entangle large whales.

Safety/operational considerations: Fixed gear fishermen cannot remove gear in a timely or practical basis. Real time reporting has limited utility if only practiced by a small percentage of vessels.

Economic concerns: In longline fisheries, fishing effort can be curtailed or modified but would have to be offset by higher catches with less depredation.

Description: This measure is similar to triggered closures or dynamic area management, requiring fishing vessels to move a certain distance from a fishing ground once a bycatch quota, depredation event, or some other quantified measure is reached (Auster et al., 2011). The distance traveled away from the area is usually specified, for a specific period of time within a particular fishing season, and may involve one or more gear types (Dunn et al., 2014). It can also be implemented as a voluntary measure to avoid interactions with depredating animals. Difficult to enforce, this method needs all vessels to adhere to restrictions to ensure success. Research could focus on their efficacy and the decision-making process for when and how they become triggered.

NOAA Fisheries has abandoned Dynamic Area Closures (DAMs) as a bycatch mitigation technique for large whales off the U.S. east coast. DAMs under the ALWTRP were originally established as a ship strike measure, and not for fisheries. Among the problems associated with DAMs in east coast pot and gillnet fisheries were that fishermen lacked an incentive to report the presence of whales, and faced insurmountable difficulties in removing gear in a timely and practical way. Furthermore, whale presence was not always observed, especially during inclement weather conditions.

Noxious bait

Concept: Unpalatable fishing bait might prevent depredating marine mammals from removing it from hooks.

Relevant fishing gear: Longlines

Target marine mammals: Odontocete cetaceans

Summary from evidence: Insufficient research exists to indicate whether this technique reduces depredation, it involves health concerns to marine mammals, and does not address the widespread removal of target catch.

Safety/operational considerations: None

Economic concerns: If it worked, it may be a cost-effective method.

Description: Making bait unpalatable could repel target species, make marine mammals sick and might be politically unpopular. Conditioned taste aversion could be a useful area of research. Focusing on bait does not address depredation on target catch, and this technique has not proven effective for other non-target species such as California sea lions (Gearin et al., 1988).

Post-entanglement release mechanisms

Concept: If marine mammal contact with gear cannot be avoided, then gear modifications can be used once contact has occurred to free them once ensnared.

Relevant fishing gear: Pots, gillnets, longlines

Target marine mammals: Mysticete and whales and odontocetes

Summary from evidence: Some of these devices work as designed; however, they likely would not free a whale before severe injury or drowning results.

Safety/operational considerations: Some adjustment to rigging and hauling practices would be required, although these could be easily learned and adopted.

Economic concerns: The expense of incorporating these devices is variable, but generally should not be cost-prohibitive, except perhaps in some small-scale non-industrial fisheries.

Description: While similar to gear with reduced strength, several devices proposed for pot lines do not require human intervention to facilitate the release of large whales. They are reviewed here for the sake of comprehensive treatment.

<u>Timed whale release</u> – A device attached to a vertical line that uses air or water compression to keep the rope secure until a certain time threshold is reached, upon which the rope would be released (Smolowitz and Wiley, 1999).

<u>Galvanic releases</u> – Metallic links on fishing gear designed to eventually dissolve, releasing any entrapped or entangled animal.

Attaching galvanic timed releases (GTRs) along parts of pot and gillnet gear could reduce the duration that an entangled whale carries trailing gear, a source of drag that can compromise the health of entangled whales. However, since the average soak time for pot gear off the northeastern U.S. is 2-3 days, fishermen would not use releases timed to dissolve sooner than this, so GTRs only potentially help a whale shed gear after several days of entanglement, not shortly after becoming entangled. Many whales drown shortly after becoming entangled because they either cannot or do not swim away with the gear and may not be able to reach the ocean surface to breathe. If they are mobile post-entanglement, dragging gear is associated with major threats to the whale's health (van der Hoop 2016). Therefore, in some cases, these releases only release line well after whales had already perished or their health already irreversibly compromised. GTRs would also need to be replaced each time the gear is set.

<u>Time tension line cutter</u> – A device tied between the bottom gear and lower end of the vertical line that would release a line-cutting blade under a pull sustained longer than the time it takes to haul the gear. The device, created by Blue Water Concepts of Maine, can only be triggered if there is a pull in two opposing directions (e.g., from a whale and an anchoring weight) (Baldwin et al., 2007).

The performance of time-tension line cutters (TTLCs) and buoy-line cutters were studied in lab and field trials and found to function as designed (Baldwin et al., 2007), although it is unclear whether using them would reduce the number or severity of whale entanglements. TTLCs function as timed releases, with the release reset once a sustained pulling force relaxes. The release time would be set longer than typical hauling duration so as not to release during that procedure. They might reduce drowning in cases where whales were unable to shed heavy bottom gear in deep water, but only if the animal maintained a constant pull on the end of rope where the release was attached while the other end was secured, such as by using an anchor. This may make them most applicable for use in heavier off-shore gear with multiple traps, or with anchored gear. One concern about TTLCs is that if they work as intended, entangled animals may more frequently carry longer trailing lines than would ordinarily be the case because, being attached near to the pot, when TTLCs cut the line they may leave longer trailing lines than with reduced breaking strength ropes. Longer lines can help teams to disentangle whales, but also have the potential to result in more wraps around the animal following the initial entanglement.

Buoy line trigger device – Created by Blue Water Concepts, this is a line-cutting device tied between the buoy marker and the top of the endline that becomes activated if a moderate pressure is exerted against a plate located at the device's lower end. It retains full strength when pulled from the buoy end. It assumes that an endline passing through a whale's mouth would eventually slide through the baleen, contact the buoy end, and the impact of the device's plate with the baleen surface would create the pressure needed to cut the line and release the buoy before it became lodged in the baleen, leaving a bitter end. It further assumes that any line remaining in the whale's mouth after the line was cut would continue to pass through the mouth and away from the animal. There is insufficient information to evaluate how frequently mouth entanglements occur involving the buoy end of a vertical line. It appears that in many instances lines become entangled in baleen before the full length of the line passes through the mouth. At the same time, weak links designed to operate under a similar principle have not been shown to be effective.

For these reasons, there currently is little support for using these devices as potential entanglement mitigation options.

Predictive forecasting

Concept: Longline fishermen who know in advance when and where marine mammals are likely to occur can avoid marine mammal bycatch by avoiding them.

Relevant fishing gear: Longlines (maybe others)

Target marine mammals: Odontocete cetaceans

Summary from evidence: Limited evidence supports the bycatch reduction benefit of this approach. Often, the most productive fishing grounds attract both fishermen and marine mammals alike. It therefore may be difficult to identify areas that are prime fishing grounds devoid of marine mammals. Habitat use by marine mammals is also variable in space and time and may change dramatically across seasons and years.

Safety/operational considerations: None

Economic concerns: Avoiding fishing-marine mammal conflicts can require expending more fuel and time to identify areas where these are less likely to occur.

Description: The identification of conflict prone regions through habitat modeling to identify areas where fishing-marine mammal conflicts might be avoided (Passadore et al., 2012; 2015a; 2015b; Peterson and Carothers, 2013) involves a high level of analytic effort with little demonstrable gains to date (e.g., Hawaii's False killer whale Take Reduction Plan). The quality of data used by models can be highly variable, as is the different equipment available to researchers for measuring them, and the analytical methods used for targeting high conflict zones. Relative to other mitigation techniques, this could be a relatively low-cost one to the industry. Long-term data series are needed to produce more reliable forecasts.

Arguably, the main difference between this technique and time-area closures is that while both areas involve identification of critical habitats, avoidance in predictive forecasting is voluntary as opposed to mandated through regulation.

Reducing the use of knots in ropes

Concept: Tying ropes together with knots rather than using splices increases the probability of whale entanglement because knots are more likely to become lodged in baleen than uniform ropes.

Relevant fishing gear: Pots

Target marine mammals: Mysticete whales

Summary from evidence: None. The dynamics of whale entanglements are poorly understood and using knots can reduce rope breaking strength, improving the ability of larger whales to part the gear.

Safety/operational considerations: Knotting is often used by pot fishermen as an expedient way to attach ropes at sea, whereas splicing takes more time.

Economic concerns: None.

Description: When tying two pieces of rope together, the use of splices creates smoother and more uniform attachments than of knots. The assumption is that knots increase the likelihood that a rope would get snagged on baleen or on an appendage as the rope slides along the animal, and upon contact with a whale would provoke a thrashing behavior increasing the probability of whale becoming entangled (NOAA 1997a).

Rope knotting remains a widespread practice in many fisheries. It is possible that knots provide locations along a rope that facilitate it becoming snagged on a whale, however there is no evidence to support this conclusion. This technique would be less relevant for sperm whales that lack baleen.

The location of knots on a rope cause that portion of the rope to have reduced breaking strength, which might help whales break the line more easily.

Reducing the vertical profile of gillnets

Concept: Reducing the vertical area in which a gillnet is deployed in the water column will help small cetaceans avoid them.

Relevant fishing gear: Gillnets

Target marine mammals: Small cetaceans

Summary from evidence: There is some evidence that the use of tie-downs can reduce bycatch of small cetaceans, although they can also lead to higher sea turtle bycatch. Lowering the depth of a gillnet may reduce bycatch but can also affect target catch.

Safety/operational considerations: None

Economic concerns: If modifying a net's vertical profile resulted in reduced marine mammal bycatch, trials should confirm that the alteration did not lead to significant reduction in target catch.

Description: The vertical profile of gillnets can be reduced intentionally by either reducing the number of meshes in the net or by using tie-downs. Tie-downs are lines that are shorter than the height of the fishing net and are connected to the float line and lead line at equal distances along the net. Tie-downs reduce the profile of the gillnet and create a more curved vertical net shape. The effect of tie-downs on marine mammal bycatch includes one experimental trial, primarily concerned with bycatch rates of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) in a sink gillnet fishery for monkfish (*Lophius americanus*) off the eastern U.S. (Fox et al., 2011). No common dolphins (*Delphinus delphis*) were caught in gillnets with tie downs in a total of 120 hauls of the combined net types, while six were caught in gillnets without tie downs (and an additional three unidentified species of dolphins). It remains unclear whether the absence of common dolphin bycatch observed in gillnets with tie-downs resulted from the decreased profile of these nets, or the increased “bagginess” of the net webbing. An analysis of U.S. observer data found the use of tie-downs was associated with lower harbour porpoise bycatch rates in gillnets (Palka 2000). Under the current U.S. Harbor Porpoise Take Reduction Program, tie downs (maximum height of 48 inches) are mandatory in large mesh gillnet fisheries in New Jersey waters and the southern Mid-Atlantic but prohibited in small mesh gillnet fisheries in the same area.

We did not identify any published literature looking at bycatch rates of marine mammals as an effect of reducing net height. However, during the workshop participants referred to a trial by U. Shahid in Pakistan where lowering the driftnet profile reduced bycatch of delphinids. The rationale of this approach would be to deploy the net so that its vertical profile occupies an area of the water column that optimizes the catch of target species but excludes all, or nearly all, marine mammals. A similar approach includes deploying a net so it fishes at a different vertical portion of the water column. Hembree and Harwood (1987) recorded a 50% reduction in small cetacean bycatch by lowering the depth of the headline (sub-surface set) although this also reduced target catch. Another trial where the vertical height of a net was reduced did not affect target catch levels while reducing non-target catch, although these were not mammals (Gray et al., 2005). He and Jones (2013) reported reductions in sturgeon bycatch in a gillnet 8-meshes deep (with 24” tie-downs spaced at 12ft) versus one that was 12-meshes deep (48” tie-downs spaces at 24ft) with some reduction in target catch. The practicability of such a modification will be dependent on the behavior of target species.

The use of tie-downs has been associated with increased bycatch rates of sea turtles (Price and Van Salisbury, 2007) but no statistically significant difference for catches of Atlantic sturgeon (Fox et al., 2011). A reduction in tie-down length from 1.8m to 0.9m was found to have no effect on sea turtle bycatch rates in a gillnet fishery in Baja California Sur, Mexico (Peckham et al., 2009), and the nets caught significantly less fish than standard nets. Gearhart et al. (2009) tested low profile nets 5m in height with standard 10m high nets in Trinidad, West Indies. Sea turtle bycatch rates were lower in the experimental nets, but so too was the volume of target catch. Reducing the number of meshes relative to standard nets also reduced the bycatch rates of Atlantic cod in a multi-species gillnet fishery in the Gulf of Maine, while increasing catches of flounder (He 2006).

Removal of floats

An experimental trial to test the effect on harbour porpoise bycatch rates in gillnets using a single floating headline compared to gillnets with polypropylene floats found that bycatch rates were significantly higher in nets without floats (SMRU 2001).

A paired trial of standard and buoy-less gillnets in Baja California Sur, California, found a reduction of sea turtle bycatch in the experimental nets in depths greater than 32m (Peckham et al., 2009). However, this reduction lacked sufficient statistical power to compare turtle bycatch rates in standard and experimental nets in depths less than 32m. A trial comparing standard bottom-set groundfish nets with 70 buoys along the float line (one every 1.7m) versus experimental nets with 15 buoys (one every 8.5m) of net reduced sea turtle (mainly loggerhead) bycatch, but also the value of the catch (Peckham et al., 2016). Experimental nets also caught fewer fish but the difference with the control net was not statistically significant.

Set geometry

Concept: Different length or configurations of lines might reduce marine mammal bycatch

Relevant fishing gear: Longlines, pots, gillnets

Target marine mammals: Cetaceans

Summary from evidence: None for longlines, except as reported by Garrison et al. (2007). For vertical lines, there may be unintended consequences, such as increasing line stiffness that might result in more severe injuries to whales.

Safety/operational considerations: Unknown

Economic concerns: Unknown; the possibility of reduced catch would need to be evaluated for individual gear sets.

Description: Altering or mixing longline deployment schemes (e.g., depth, orientation, split sets) might reduce marine mammal interactions. This approach would likely apply to anchored gear because the geometry of floating gear is less controllable under different wind, wave, and tidal conditions. Garrison (2007) found reduced rates of interactions of pilot whales in longline gear that were shorter sets (mainline length < 20 miles) as measured by damage to target catch.

For pot and gillnet gear, this technique involves reducing the probability of entanglement by using the minimal length of rope or gillnets, to reduce the overall amount of gear in the water column. It includes avoiding wet storage of gear or keeping gear in the water even though it is not being actively fished. It is mainly discussed as a voluntary measure in U.S. fisheries.

Stow buoy lines at depth except when hauling

Concept: Whales cannot become entangled in lines retained at the sea floor within containers or when pots use inflatable bags to bring them to the surface for hauling.

Relevant fishing gear: Pots

Target marine mammals: Mysticete whales

Summary from evidence: The absence of endlines in the water column would undoubtedly eliminate entanglements in these ropes, and no whales have been reported caught in this gear where it is used in southeast Australia.

Safety/operational considerations: The greatest concern expressed by fishermen is that without surface buoys identifying the presence of gear underwater, there will be an increased likelihood of trawl fishermen dragging their gear away or tangling it, and that other pot fishermen may be more likely to set gear on top of one another leading to tangled lines. These outcomes would create lost or damaged gear, and more difficulty in retrieving gear dragged to a different location. Where gear density is high, and areas are not zoned for different types of fishing gear, these “ropeless” techniques will require a system to identify bottom-set gear to all fishermen using the same fishing grounds.

Economic concerns: Existing technologies such as acoustic releases and supporting systems are costly and may not eliminate the gear conflicts described above.

Description: This technique involves retention of buoy lines at or near the sea-floor except during setting and hauling. Haul lines are brought to the surface using acoustic releases, digital timers, galvanic timed releases, or inflatable bags. Ropes and buoys may be encased within mesh bags, canisters, or on spools. Buoy lines are called to the surface by either: (1) the use of a galvanized metal clip that chemically dissolves in sea water; (2) using a programmable release set to a specified time in the future; or (3) an acoustically transmitted command that activates a mechanical release. Another approach might dispense with ropes altogether, by fishing with autonomous traps. Such “rope-less” techniques would involve retrieving gear by grappling or using newer technologies, some of which are already used in oceanographic equipment. Pots at the bottom could be designed to deploy and resurface using surface-based acoustic commands, or robotic underwater vehicles might be deployed to carry haul lines that would be attached to rope-less pots for retrieval.

Of all the potential whale entanglement prevention techniques, this is considered the safest one for whales, essentially making other parts of the gear (nets and horizontal ropes in the case of gillnets and groundlines, when used) the sole source of entanglement risk.

> “Complete removal of buoy lines is recognized as the most ‘whale safe’ technique for utilization of fixed gear” (NMFS 2000, p. 14)

Bottom-stowed vertical lines are not a new idea and have been used in Australia’s New South Wales rock lobster pot fishery for more than a decade (Liggins 2013). Researchers and fishermen in the eastern U.S. have carried out three separate trials of prototype units that contained buoys and buoy lines near the ocean floor. DeAlteris (1999) describes a modified lobster trap in which the buoys, a line canister, and acoustically triggered mechanical release were contained. In three separate deployments, two in 150’ depth and one in 300’, the releases successfully sent the line to the surface in 47/50 attempts, 2 resulted in line snagging. Hopkins and Hoggard (2006) tested the performance of *Subsea Sonics* burn wires as a potential release mechanism for lobster pots, achieving a 100% success rate from as far as 926m away from the vessel. The same basic design of DeAlteris (1999) was later tested with a drum gillnet and lobster trap trawl in southern New England and on the eastern shelf of George’s Bank, where 57% of the haul line and buoys were released successfully in 129 attempts (Allen and DeAlteris, 2007). A further 8% released successfully although the line surfaced more slowly. The remaining attempts were failures, involving “buoy up when gear hauled from other end” (15%), line snags (12%), no release (7%) and other (1%).

These trials demonstrate that the technology is promising. However, three primary challenges explain why bottom-stowed vertical lines are not widely used. First, surface buoys provide visual markers to all fishermen and boaters about the presence of gear underwater. Eliminating them would lead to a higher incidence of gear conflicts. In heavily utilized fishing grounds, fishermen may experience a higher likelihood of setting gear on top of one another. Second, acoustic releases, which give fishermen the greatest flexibility in determining when the gear can be retrieved, can be expensive, requiring at least one transponder, mechanical release, and a containment system for at least one vertical line per gear set, as well as deck-based acoustic signal transmitters. Third, depending on how the rope is placed into a container as well as how it is released, there may be a higher incidence of the rope becoming tangled or snared at the instance of retrieval. Fourth, regulators have expressed concern that the inability to monitor gear from the ocean surface might obscure unregulated fishing. Galvanic and digitally timed releases would eliminate the high cost of acoustic releases, but the latter provide the most flexibility in terms of retrieval and the ability to retrigger mechanical releases that may not operate after the first attempt (Partan and Ball, 2016). Galvanic timed releases (GTRs) are the least reliable in activating at exactly the desired release time, and a fisherman may not always return to the gear at the anticipated time of retrieval. For these reasons, except for acoustic releases, buoy lines may occur within the water column for a portion of the total gear set time, which would create a partial entanglement risk. Of all the techniques, an “at-call” acoustic release system is the one that removes 100% of the risk of whale encounter with the buoy line except: (1) if there is a substantial length of rope connecting the pot/gear and the bag/container of the submerged buoy line; (2) the very short period during hauling of the gear post-release; or (3) in the event of system failure (e.g., the buoy line becoming tangled post-release before the buoys reach the surface, or if fishermen deploy them incorrectly).

Partan and Ball (2016) describe a prototype spool that dispenses entirely with a container for the haul line and buoys, and instead uses a flotation spool consisting of a metal frame and positively buoyant syntactic foam. This device is currently undergoing tests at sea, including on-board offshore pot fishing vessels off the eastern U.S. Galvanized metal has also been proposed to secure hauling lines in a coil at the ocean floor until the release dissolves, thereby freeing a buoy that would bring the hauling line to the surface (Salvador et al., 2002).

It is difficult to foresee any instances in which using this technique would not prevent whale entanglements. Introducing a sound source into the ocean can alter the behavior of marine animals and ecosystems (Tyack 2008); however, these types of acoustic signals would be triggered infrequently and have not been shown to significantly affect large whales. Gear might be lost due to malfunctioning releases, however having a system for communicating with gear using acoustics increases the likelihood of relocating gear for retrieval by grappling. Furthermore, having vertical lines on the opposing end of a long gear set (e.g, >30 pots), where both are submerged and secured with remote releases, or the use of a weaker line at this terminal end of the set, can serve as back-up retrieval systems if the primary hauling line fails or is lost. Although current remote retrieval systems are expensive, their use might help recoup lost revenues and high gear replacement expenses from lost gear. By one estimate, this can total nearly US$17 million each year for the lobster fishery in Lobster Management Area 1 in the northeastern U.S. (Bob Glenn, Massachusetts Department of Marine Fisheries, *unpublished study*).

Sinking or neutrally buoyant groundline

Concept: Negatively buoyant ropes connecting strings of pots remain on the seabed rather than looping up into the water column so they are less likely to pose entanglement risk to baleen whales.

Relevant fishing gear: Pots

Target marine mammals: Mysticete whales

Summary from evidence: None, however it seems probable even though many whales feed along the sea floor that there is a reduced probability they will become entangled in these ropes on the seabed than higher up in the water column.

Safety/operational considerations: Lobster pot fishermen in the Gulf of Maine report many concerns including increased incidence of ropes becoming hung up on rocks, increased sedimentation of ropes, and a reduction in the operational life of ropes.

Economic concerns: Because these ropes rest more on the sea floor, more sediment collects within the fibers, more chafing occurs on rocks and traps, requiring more frequent replacement than positively buoyant rope.

Description: Having the line that connects pots to one another be negatively buoyant so it lays on or near the seafloor versus up in the water column, eliminating loops of groundline rope formed by slack, positively buoyant ropes extending upwards into the water column and reducing the risk of entanglement to bottom-feeding whales.

For a complete summary of this technique, see Ludwig et al. (2016).

Time of day/night

Concept: Gear might be deployed when adequate target catch is attainable but marine mammals are less abundant.

Relevant fishing gear: Gillnets, Longlines

Target marine mammals: All

Summary from evidence: None, but has been poorly investigated

Safety/operational considerations: Unknown

Economic concerns: Unknown

Description: This strategy would set gear when marine mammals are less active, but target catch is still abundant. Garrison (2007) examined this, among other variables, to determine which were correlated with higher bycatch of pelagic cetaceans (pilot whales and Risso's dolphins). Time of day did not explain bycatch rates. A literature review of environmental, operational, gear design, or bycatch species behavior/psychology factors that might correlate with bycatch rates uncovered no study on set time of day for marine mammals (Northridge et al., 2017).

This tactic is infeasible for some fisheries if the target species and marine mammals are both actively feeding at the same time.

Trap (pot) guards/net modification

Concept: Marine mammals, mainly pinnipeds are not able to enter pots or trap nets if barriers are inserted in the entrance, the entrance itself is made smaller, or stronger mesh netting is used.

Relevant fishing gear: Pots/Trap nets

Target marine mammals: Pinnipeds, small cetaceans, otters

Summary from evidence: These devices work effectively, mainly for pinnipeds for which they have mostly been developed and tested.

Safety/operational considerations: None reported

Economic concerns: The use of this technique does not appear to negatively affect target catch levels or size classes.

Description: This technique involves different types of modifications to fish pots/traps so that marine mammals find it more difficult to prey on bait or target catch, and also avoid getting trapped which can result in drowning. One tactic uses a pole or spike inserted inside a pot so that its other end extends into the pot opening, with the intention of preventing pinnipeds, cetaceans, or otters from reaching their heads into the pot and removing target catch or bait. With the right design, these poles effectively deter depredation for Australian sea lions (Goldsworthy et al., 2010). Another technique involved modifying the size and/or composition of the innermost opening of the pot entrance to prevent entry by marine mammals. Using solid rings of steel of particular diameters prevent seals in the Baltic Sea from gaining entry to cod pots (Königson et al., 2015). Hatfield et al. (2011) showed that decreasing the diameter of crab and shellfish pots off the west coast of the US would reduce the entry rate of sea otters (*Enhydra lutris*), without—at least at some diameters—affecting the target catch of Dungeness crab (*Cancer magister*). Constructing pots out of stronger mesh, such as *Dyneema*, makes it harder for seals to tear holes into netting to get access to target catch or bait (Suuronen, 2006). Finally, included here is changing how bait bag openings were secured with bungee cords in Florida's blue crab pot fishery, a method that eliminated nearly all interactions with bottlenose dolphins (Noke and Odell, 2002).

Vessel noise reductions

Concept: If the noises produced by fishing vessel engines and fishing activities, especially mechanical hauling, were lowered, marine mammals would be less likely to cue in on the sounds and interact with the gear.

Relevant fishing gear: Longlines

Target marine mammals: Odontocete cetaceans, pinnipeds

Summary from evidence: This technique has not been adequately evaluated.

Safety/operational considerations: None identified.

Economic concerns: Vessels and onboard machinery such as haulers would need to be replaced or retrofitted to quiet their acoustic output, perhaps involving considerable expense.

Description: Reducing the probability that marine mammals detect fishing activity by visual or other cues, by altering acoustic footprints or vessel loitering (Gilman et al., 2006; Thode et al., 2007). Whales seem to home in on vessel noises, so quieting vessels could be effective. Understanding the extent to which marine mammals use cues for finding vessels would be required to evaluate the potential of this technique.

Visual deterrents

Concept: Whales might avoid gear if they could see it better.

Relevant fishing gear: Pot and gillnet ropes

Target marine mammals: Mysticete whales

Summary from evidence: Trials in well-lit surface waters show that modifying rope color can produce a change in avoidance time in some whale species

Safety/operational considerations: None identified

Economic concerns: Simply changing rope color should not affect target catch nor the cost of fishing ropes, however other enhancements such as adding LEDs or fluorescence would add significantly to the cost of the ropes.

Description: This technique involves altering the color, luminosity, or appearance of fishing ropes to make them more visually detectable by large whales.

Preliminary field work on rope coloration indicates that, for right whales, red and orange ropes are detectable near the surface during daylight hours at nearly twice the distance than for green ropes, a finding that was statistically significant (Kraus et al., 2014). In that same experiment, black ropes were detectable at distances greater than green, but less than red/orange, with the difference between black and red/orange not significant. In another experiment, Kot et al. (2012) found that minke whales exhibited statistically significant behavioral responses to colors of rope in nearshore habitat. Although the strongest behavioral changes were reported during trials with white and black ropes, behavioral changes occurred at distances approaching 100m; however, behavior changes as this distance were not likely a visual response (Kot et al., 2012). One other experiment on whale eyesight was the early test for sonar in humpbacks (Beamish 1978). In that study, a humpback was blindfolded and run through a maze. With blindfolds on, the whale failed to navigate the maze, but with blindfolds off, the whale successfully completed the maze, even at night. In comparing cetacean catch rates in yellow nets off Durban versus black-colored shark nets from other parts of South Africa, no differences were found (V. Peddemors, *pers. comm.*). However, these data were not collected within the same locality during the same period, nor did they control for other variables that might explain the observed results.

Altering rope color is an attractive option for whale entanglement prevention because it is relatively easy to do and should not increase the cost of fishing gear if a phased-in period is allowed that mimics the natural replacement regime of gear by fishermen. Furthermore, altering color characteristics could be widely applicable to a variety of gear types, including aquaculture systems. On the other hand, concerns have been raised about the effects of making gear more detectable, and the possibility of eliciting a curiosity or other attractant response from some species.

Using illuminated ropes, the hypothesis is that with proper constant or strobe illumination, large whales could be alerted to the presence of the gear. The illumination should create a halo effect around the line artificially increasing the size of the gear, thus allowing the large whale a greater chance of visually detecting the line in time to avoid interaction. As with any gear modification designed to increase detection, environmental conditions must be ideal for the animal to detect the gear in time for an avoidance response.

Recreational fishermen and commercial fishing have used lights of various power sources on the surface and below the water to attract bait fish that lure game fish in for capture (Watson et al., 2005). Chemical light sticks placed near hooks in longline fisheries have increased turtle bycatch interactions (Watson et al., 2005; Southwood et al., 2008), so the impact on different non-target bycatch species would have to be addressed. LEDs were part of a detection experiment with North Atlantic right whales but were quickly abandoned due to reliability issues. No data were collected from the experiment using the LEDs (S. Kraus, *unpublished data*).

Wang et al. (2010) experimented with shapes and various types of illumination, including LEDs, to deter turtle bycatch in a gillnet fishery. The LEDs showed the most promise with a turtle bycatch reduction of 40% and having negligible impact on catch or catch value.

Add-on devices of various sizes and geometries can be attached to fishing gear ropes to aid in visual detection by passing mysticete whales. These designs increase the surface area of a rope and, ideally, can be used with existing commercial and recreational rope haulers. Features of these devices that could have application for deterring whales are streamers, finger-like projections, and spinning rotors. Under moderate-to-strong flow conditions, the hydrodynamic drag from some of these devices may generate a passive, turbulence-based acoustic cue potentially aiding detection by whales in the vicinity. Very few *in situ* experiments testing for behavioral responses of large whales to add-on devices have been conducted. Results from field experiments with short lengths (20cm) of flexible rope "whiskers" attached at 1m intervals along vertical buoy lines suggested that minke whales may be able to detect ropes with these attached devices more readily than buoy lines without them (Figure 1; Kot et al., *in submission*). Pilot tests with LED units and 20cm mylar streamers were insufficient to draw any conclusions in right whale responses (S. Kraus, *unpublished data*).

Color patterns applied to ropes also have the potential to enhance visual detection of fishing gear by mysticete whales. High-contrast bands, stripes, and zig zag color patterns are more detectable against uniform versus heterogeneous backgrounds by terrestrial mammals (Stevens et al., 2008) and likely have application in underwater rope experiments with marine mammals.

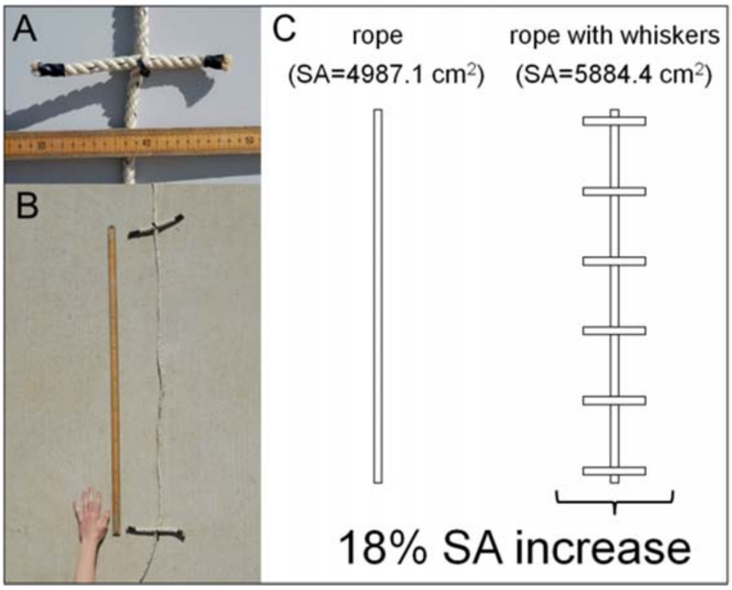

Figure 1. Experimental rope with 20cm-long “whisker” add-on devices that increase standard rope surface areas (SA) by 18% (Kot et al., in submission).

Table 3. Summary table on visual deterrents tested or proposed for baleen whales.

Visual Deterrents	Evidence for whales	Fabrication Feasibility	Research Needed	Likelihood of Effectiveness	Cost	Application Concerns	Publications
Colored Rope (red, orange, black)	right, minke, fin	High	Lab, field, more species, location and context-specific studies	High in surface waters; depth and light dependent; species dependent; fishery density dependence	Low	Distance of detection and avoidance capabilities of large whales	Bischoff et. al., 2012; Kot et al., 2012; Meredith et al., 2013; Fasick et al., 2000
LED’s and other light sources	None	Unknown	Response of whale	Unknown	Med.	Attractant for some sea turtle species; target catch reduction	Wang et al., 2007, 2010, 2013; Watson et al, 2005; Southwood et al., 2008
Streamers, rope area enhancers	minke, humpback, fin	High	Field studies	Some encouraging results with minkes	Low	Time to rig gear	Kot et al., in submission
Stripes and other patterns	None	Medium	Field studies	Unknown	Unk.	Unknown	Stevens et al., 2008; Kitaoka an Ashida, 2003; Zanker and Walker, 2004

Underwater visibility is likely to be a major factor for whales in detecting objects underwater, regardless of color or other features that enhance visibility. The data from Kot et al (2012) and Kraus et al (2014) suggest that during daylight, and in water conditions where a minke or North Atlantic right could see the ropes at least four meters away, an avoidance response by the whales can prevent collisions with ropes. Underwater visibility in temperate latitudes is generally less than 20m on the shelf, and frequently below 10m in coastal waters. The change in response distances in Kraus et al. (2014) throughout the day indicates that the effectiveness of high contrast orange/red ropes is still subject to variation in lighting. The lower “change of behavior” distances, observed during the early morning and in the evening, suggest that the high contrast effect of orange and red may not be as effective at night. However, because whales are rod monochromats (Meredith et al., 2013), and rods are excellent low-light receptors, it may be that there is sufficient information in the night-time space light to detect ropes that contrast with even the low-level background light present at night.

The Kraus et al. (2014) trials demonstrated that right whales want to avoid hitting ropes and will make drastic maneuvers to avoid collisions when they detect them. Red and orange ropes were found to increase the distance of detection to a point where whales have ample distance to execute successful avoidance behaviors. This assumes the environmental conditions and the transit rate of the whale allows that avoidance to be possible. At the very least, eliminating green and white ropes from the fixed gear fishery is likely to reduce collision probabilities in all fisheries that encounter right whales.

The studies carried out to date on improving visibility of ropes show encouraging results, suggesting that this technique should be further evaluated. So far, trials have only been carried out with NARWs and minke whales, because mysticetes are all rod monochromats the results may be applicable for all baleen whales. However, detection and avoidance of fishing gear may be somewhat dependent upon the antecedent behavior of the whales, and there may be different levels of alertness for migrating, feeding, and mating whales. Further, there are likely different levels of entanglement risk due to swimming depth, behavior at night, or whether an animal is alone, or in a group. Differences in behavioral responses between species, populations, and even individuals are also possible. Many anecdotal reports exist of humpback whales demonstrating what appears as playful interaction with ropes and other fishing gear. Selection of locations and species for visual deterrent testing need to take these factors into account, as well as the underwater visibility as described above. If testing whale behavioral responses to visual stimuli in a controlled experiment, it will be important to collect behavioral data near the objects being encountered. If analyzing bycatch rates of large whales in which visual deterrents have been employed, it will be important to fully understand the behavioral context of the whales in the area.

Whale-free buoy

Concept: More whale entanglements could be avoided if buoys had a tapered shape that increased the likelihood they would not get hung up on a whale flipper.

Relevant fishing gear: Pot and gillnet ropes

Target marine mammals: Mysticete whales

Summary from evidence: None; there is no information indicating that the first point of encounter between whales and ropes in these gear is along the flipper, and many suspect, based on examination of whale behavior and the configuration of ropes entangling large whales, that the mouth region may often be the initial area of contact. With so many baleen entanglements, this design may just as likely increase entanglement risk in the mouth, and possibly also increase their severity.

Safety/operational considerations: None identified

Economic concerns: Probably minimal, involving replacement of surface buoys

Description: This is a buoy designed with a flexible, tapered stem made of urethane or some other plastic (Goudey, 2004). Conceived of as an alternative to the typical bullet-shaped lobster buoy used in the northeastern U.S. that attaches directly to a line or first to a stiff plastic stick, it is intended to slip more easily around a whale flipper rather than get lodged onto the animal following contact.

The design and flexibility of the device seem practical for fishing and would probably be less likely to result in a whale entanglement if the flipper were the initial point of contact with the fishing gear. However, many entanglements involve the mouth, and the design appears optimal for becoming lodged in baleen and even damaging a larger area of baleen plates if contact occurred. Also, the design runs counter to the concept of a weak link; its tapered design was intended to slide smoothly around a body part, whereas a weak link on a vertical line is supposed to function by severing at a point where the line can no longer slide freely. It is therefore at odds with current U.S. regulations for many east coast fisheries that use buoy lines. Seeing as it might interfere with the proper functioning of weak links on buoy lines, and that it might increase the probability or severity of mouth entanglements, use of this device should be discouraged unless entanglements were known to mainly occur from initial contact with the whale flipper.

It would be instructive to know the extent to which entanglements occur during feeding, and the proportion of entanglements that occur because of initial contact with the head or mouth versus the flipper. This would help identify which among several bycatch mitigation techniques, including a tapered buoy design, would have more promise.

OTHER PREVENTION STRATEGIES

Other strategies may assist fisheries and fishery managers in achieving bycatch reduction targets. These include reducing overall fishing effort resulting in less gear in the water, and improving fishery management to reduce overfishing while maximizing profits leading to reductions in bycatch of marine mammal populations (Burgess et al., 2018). Some have suggested that catch shares might result in reduced bycatch by eliminating the incentive to fish as hard and fast as possible to reach quota, although this has not been studied.

GEAR SWITCHING

At least for gillnets, several researchers have examined the potential of fishing with alternative gear to see if fishermen can achieve the same catch levels without endangering marine mammals. Table 4 lists trials undertaken to evaluate alternative fishing gears for reducing marine mammal bycatch in gillnets. These trials assessed three different alternative types of gear to gillnets—traps, longlines, or trawls—and focused primarily on comparing target catch abundance and size selectivity with assumptions about reduced marine mammal bycatch, or recorded comparisons of both.

Table 1. Gear switching trials undertaken to determine the potential of gillnet alternatives for reducing bycatch or interactions of marine mammals.

Location	Target catch	Marine Mammal Bycatch	Alternative Gear Tested	Result	Reference
Baltic Sea (Sweden)	Cod (*Gadus morhua*)	Seals	Longline	Comparable catch levels; reduced seal interactions	Vetemaa and Ložys, 2009
Baltic Sea (Sweden)	Cod	Harbor porpoise	Longline	Comparable catch levels based on logbook data; seasonally dependent	(Königson and Hagberg, 2007)
Iceland	Cod	Harbor porpoise	Longline	Eliminated bycatch of porpoise but still have seal bycatch	H. Einerssen, *pers. comm.*
Southwest Atlantic (northern Argentina)	Primarily whitemouth croaker *(Micropogonias furnieri)* and stripped weakfish (*Cynoscion guatucupa)*	Franciscana dolphin	Handline	Bottom hand-lines had comparatively lower operational expenses, had the same relative selectivity, caught species with the highest value in the local market and of better quality, required shorter soak times, and lasted longer than gillnets	Bordino et al., *unpublished data*
Baltic Sea (Sweden)	Cod	Grey seals and harbor seals	Traps	Comparable catch levels but with seasonal variability; no bycatch of seals when using a SED (Seal Excluder Device)	Königson et al., 2015
Baltic Sea (Germany)	Cod (*Gadus morhua*) and other fishes	Harbor porpoise	Traps	Higher species selectivity (cod) in traps, but CPUE higher with gillnets; no bycatch of porpoise in either gillnets or traps, but seabirds caught only in gillnets	Pusch, 2011
Gulf of California	Shrimp (*Penaeus stylirostris* and *P. californiensis*)	Vaquita	Traps	Inconclusive; No shrimp caught	Walsh et al., 2004
Gulf of California		Vaquita	Trawls	Several trials over multiple years indicated that experimental trawls did catch shrimp	Aguilar-Ramirez and Rodriguez-Valencia, 2012

Several gear-switching trials undertaken to date have produced encouraging results indicating a high potential for this strategy to help reduce marine mammal bycatch in gillnets. In some cases, catch of target species was comparable between the gears tested, and/or achieved improved size class selectivity and quality. Longlines and other gear types generally have another advantage over gillnets in that they often have shorter soak times, which reduces how long the gear —and any fish caught— are exposed to potential interactions with marine mammals. Longlines also have a greater chance of hauling in live or fresher catch than gillnets with their longer soak times, which can increase the quality of and price paid for the catch. If gillnet alternatives can yield a fisherman approximately the same or greater returns while reducing marine mammal bycatch, the strategy would represent a win-win situation in fisheries facing this problem.

Even when fishing trials indicate the potential of using alternative gear, rarely do they also include complementary studies (economic, political, social, cultural) that can provide the practical considerations for implementing gear switching strategies. An advisable next step should build on encouraging results to lower marine mammal bycatch using alternative gear by supporting studies evaluating economic incentives and other practical considerations between different fishing gears. It would be a shame to abandon this strategy for lack of follow-up from the initial experiments when they have shown initial promise. Furthermore, because there is often resistance to change within fisheries, persistence on the part of managers and scientists would likely need to help advance this strategy.

Justification for considering the use of alternative gear types should be based on adequate scientific evidence that 1) the bycatch of the animals of concern is significantly reduced, 2) catches of target species are comparable to gillnets or the fishing gear in concern, and 3) there are few or no negative consequences to other species or ecosystems.

SPECIAL MEASURES – CODES OF CONDUCT/PRACTICE

Several practices under codes of conduct involve operational practices that do not obviously fall under the other measures discussed in this document. These include conservation and management measures prohibiting the direct setting on or encirclement of dolphins to catch tuna in fishing areas covered under the *Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean and the Indian Ocean Tuna Commission*.

As another example, under the South Australia Sardine Association 2015 Code of Practice (aasshttp://www.sasardines.com.au/wp-content/uploads/2015/07/2015-Wildlife-Interactions-Code-Of-Practice-13.pdf), fishing vessels are to adopt several operational procedures. These include: 1) avoiding known areas of dolphin aggregation; 2) notifying the skipper of the presence or absence of dolphins before setting gear; 3) delaying or relocating fishing activity if dolphins are detected; 4) initiating release procedures without delay when encircled dolphin(s) are detected, including stopping the net roll, dropping one end of the net and guiding the animal out of it; and 5) abort fishing altogether if attempts to release encircled dolphins failed. Some of these measures may be directly responsible for reductions in dolphin bycatch (Hamer et al., 2008).

Under the Elements of the Code of Fishing Practice (CoP) for the Australia blue grenadier (*Macruronus novaezelandiae*) fishery (Tilzey et al., 2006), New Zealand deepwater trawl fisheries (Deepwater Group 2017), and with the Southeast Trawl Fishing Industry Association (SETFIA 2007) measures include rapid hauling, delaying deployment if seals are sighted, release of animals that are caught, closure of net during recovery, not dumping offal, actively steaming away from seals before shooting nets, undertake shooting and trawling as quickly as possible, removal of meshed fish ("stickers") prior to use, no discarding of unwanted fish or offal on fishing grounds, where possible adopt techniques to close trawl opening during recovery to minimise opportunities for seals to enter net, not executing turns or changes of direction with doors deployed and net mouth open near surface, and after gantry lights switched off during night trawling if large numbers (>5) of marine mammals congregate around vessel when gear is hauled the vessel should steam away from them before setting gear again. Tilzey et al. (2006) indicate that adopting this code reduced seal bycatch by half following implementation.

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APPENDIX 3A

Species, subspecies and subpopulations of marine mammals considered in this report (IUCN 2017)

	IUCN STATUS	FAO Fishing Region
Order Carnivora		
Family Ursidae		
Ursus maritimus Phipps, 1774. Polar bear	VU	Arctic Sea; Atlantic – northeast, northwest; Pacific – northeast, northwest
Family Mustelidae		
Enhydra lutris (Linnaeus, 1758). Sea otter	EN	Pacific - northwest, northeast, eastern central
E. l. kenyoni Wilson, 1991. Eastern sea otter	[not assessed]	
E. l. lutris (Linnaeus, 1758). Western sea otter	[not assessed]	
E. l. nereis (Merriam, 1904). Southern sea otter	[not assessed]	
Lontra felina (Molina, 1782). Chungungo, marine otter	EN	Atlantic – southwest; Pacific – southeast
Neovison macrodon (Prentis, 1903). Sea mink (extinct)	EX	Atlantic – northwest
Suborder Pinnipedia		
Family Otariidae		
Arctocephalus australis (Zimmermann, 1783). South American fur seal	LC	Atlantic – southwest; Pacific – southeast
A. australis (Peruvian/Northern Chilean subpopulation)	VU	Pacific - southeast
A. a. *australis* (Zimmermann, 1783)	LC	Atlantic – southwest; Pacific – southeast
Arctocephalus forsteri (Lesson, 1828). Long-nosed fur seal, New Zealand fur seal	LC	Indian Ocean – eastern; Pacific – southwest
Arctocephalus galapagoensis Heller, 1904. Galapagos fur seal	EN	Pacific – southeast
Arctocephalus gazella (Peters, 1876). Antarctic fur seal	LC	Atlantic – southwest, southeast, Antarctic; Indian Ocean – Antarctic, eastern; Pacific – southwest, Antarctic
Arctocephalus philippii (Peters, 1866). Juan Fernandez fur seal	LC	Pacific – southeast
A. townsendi Merriam, 1897. Guadalupe fur seal	LC	Pacific – eastern central
Arctocephalus pusillus (Schreber, 1775). Afro-Australian fur seal	LC	Atlantic – southeast; Indian Ocean – eastern, western; Pacific – southwest

	IUCN STATUS	FAO Fishing Region
A. p. pusillus (Schreber, 1775). Cape fur seal	LC	Atlantic – southeast; Indian Ocean – western
A. p. doriferus Wood Jones, 1925. Australian fur seal	LC	Indian Ocean – eastern
Arctocephalus tropicalis (Gray, 1872). Subantarctic fur seal	LC	Atlantic – southwest, southeast, Antarctic; Indian Ocean – eastern, western, Antarctic; Pacific – southeast, southwest
Callorhinus ursinus (Linnaeus, 1758). Northern fur seal	V	Pacific – northeast, eastern central, northwest
Eumetopias jubatus (Schreber, 1776). Steller sea lion, northern sea lion	NT	Pacific – northwest, eastern central, northeast
E. j. jubatus (Schreber, 1776). Western Steller sea lion	EN	Pacific – northeast, northwest
E. j. monteriensis (Gray, 1859). Loughlin's Steller sea lion	LC	Pacific – eastern central, northeast
Neophoca cinerea (Peron, 1816). Australian sea lion	EN	Indian Ocean – eastern
Otaria byronia (Blainville, 1820). South American sea lion	LC	Atlantic – southwest; Pacific – southeast
Phocarctos hookeri (Gray, 1844). New Zealand sea lion, Hooker's sea lion	EN	Pacific – southwest
Zalophus californianus (Lesson, 1828). California sea lion	LC	Pacific – eastern central, northeast
Zalophus japonicus (Peters, 1866). Japanese sea lion (extinct)	EX	Pacific – northwest
Zalophus wollebaeki Sivertsen, 1953. Galapagos sea lion	EN	Pacific – southeast
Family Odobenidae		
Odobenus rosmarus (Linnaeus, 1758). Walrus	VU	Arctic Sea; Atlantic – northwest, northeast; Pacific – northeast, northwest
O. r. divergens (Illiger, 1815). Pacific walrus	DD	Arctic Sea; Pacific – northwest, northeast
O. r. rosmarus (Linnaeus, 1758). Atlantic walrus	NT	Atlantic – northwest, northeast
Family Phocidae		
Cystophora cristata (Erxleben, 1777). Hooded seal	VU	Atlantic – northeast, northwest
Erignathus barbatus (Erxleben, 1777). Bearded seal	LC	Arctic Sea; Atlantic – northwest, northeast; Pacific – northwest, northeast
E. b. barbatus (Erxleben, 1777). Atlantic bearded seal	LC	Arctic Sea; Atlantic – northwest, northeast
E. b. nauticus (Pallas, 1881). Pacific bearded seal	LR/LC	Arctic Sea; Pacific – northwest, northeast
Halichoerus grypus (Fabricius, 1791). Gray seal	LC	Atlantic – northeast, northwest
H. grypus (Balitc sea subpopulation)	LC	Atlantic - northeast
H. g. grypus (Fabricius, 1791). Baltic gray seal	LC	Atlantic - northwest

	IUCN STATUS	FAO Fishing Region
H. grypus macrorhynchus Hornschuh & Schilling, 1851	LC	Atlantic - northeast
Histriophoca fasciata (Zimmerman, 1783). Ribbon seal	LC	Arctic Sea; Pacific – northwest, northeast
Hydrurga leptonyx (Blainville, 1820). Leopard seal	LC	Atlantic – southwest, Antarctic; Indian Ocean – Antarctic; Pacific – southeast, southwest, Antarctic
Leptonychotes weddellii (Lesson, 1826). Weddell seal	LC	Atlantic – southwest, southeast, Antarctic; Indian Ocean – eastern, Antarctic; Pacific – southeast, southwest, Antarctic
Lobodon carcinophaga (Hombron and Jacquinot, 1842). Crabeater seal	LC	Atlantic – southeast, southwest, Antarctic; Indian Ocean – western, eastern, Antarctic; Pacific – southeast, southwest, Antarctic
Mirounga leonina (Linnaeus, 1758). Southern elephant seal	LC	Atlantic – southwest, southeast, Antarctic; Indian Ocean – western, eastern, Antarctic; Pacific – southwest, southeast, Antarctic
Mirounga angustirostris (Gill, 1866). Northern elephant seal	LC	Pacific – northwest, northeast, eastern central
Monachus monachus (Hermann, 1779). Mediterranean monk seal	EN	Atlantic – eastern central; Mediterranean and Black Sea
Neomonachus tropicalis (Gray, 1850). Caribbean monk seal, West Indian monk seal (extinct)	EX	Atlantic – western central
Neomonachus schauinslandi (Matschie, 1905). Hawaiian monk seal	EN	Pacific – northwest, eastern central
Ommatophoca rossii Gray, 1844. Ross seal	LC	Atlantic – southwest, Antarctic; Indian Ocean – Antarctic; Pacific – Antarctic
Pagophilus groenlandicus (Erxleben, 1777). Harp seal	LC	Arctic Sea; Atlantic – eastern central, northeast, western central, northwest
Phoca vitulina Linnaeus, 1758. Harbor seal, common seal	LC	Atlantic – northeast, northwest; Pacific – eastern central, northeast, northwest
P. v. vitulina Linnaeus, 1758. Eastern Atlantic harbor seal	LC	Atlantic – northeast
P. v. mellonae Doutt, 1942. Ungava harbor seal	EN	Altantic - northwest (Quebec, only)
P. v. stejnegeri J. Allen, 1902. Kuril Seal	DD	Pacific – northwest, northeast
P. v. cocolor DeKay, 1842. Western Atlantic harbor seal	LC	Atlantic – western central, northwest
P. v. richardii (Gray, 1864). Eastern Pacific harbor seal	LC	Pacific – eastern central, northeast
Phoca largha Pallas, 1811. Spotted seal, largha seal	LC	Arctic Sea; Pacific – northwest, northeast
Pusa hispida (Schreber, 1775). Ringed seal	LC	Arctic Sea; Atlantic – northeast, northwest; Pacific – northeast, northwest
P. h. hispida (Schreber, 1775). Arctic Ringed seal	LC	Arctic Sea; Atlantic – northwest, northeast; Pacific – northwest, northeast

	IUCN STATUS	FAO Fishing Region
P. h. botnica (Gmelin, 1788). Baltic ringed seal	LC	Atlantic – northeast
P. h. ochotensis (Pallas, 1811). Okhotsk ringed seal	LC	Pacific – northwest
P. h. ladogensis (Nordquist, 1889). Lake Ladoga seal	VU	Atlantic – northeast
P. h. saimensis (Nordquist, 1889). Saima seal	EN	Atlantic – northeast
Pusa caspica (Gmelin, 1788). Caspian seal	EN	Caspian Sea not in global FAO Fishing Area maps!
Pusa sibirica (Gmelin, 1788). Baikal seal	LC	Lake Baikal not in global FAO Fishing Area maps!
Order Cetartiodactyla		
CETACEA		
MYSTICETI		
Family Balaenidae		
Balaena mysticetus Linnaeus, 1758. Bowhead whale, Greenland whale	LC	Arctic Sea; Atlantic – northwest, northeast; Pacific – northwest, northeast
B. mysticetus (Bering-Chukchi-Beaufort Sea subpopulation)	Lower Risk/conservation dependent	Arctic Sea; Pacific – northwest, northeast
B. mysticetus (Okhotsk Sea subpopulation)	EN	Pacific – northwest
B. mysticetus (Svalbard-Barents Sea (Spitsbergen) subpopulation)	CR	Atlantic – northeast
B. mysticetus (Hudson Bay-Foxe Basin subpopulation)	[not assessed]	Atlantic – northwest
B. mysticetus (Baffin Bay-Davis Strait subpopulation)	[not assessed]	Atlantic – northwest
Eubalaena glacialis (Müller, 1776). North Atlantic right whale	EN	Atlantic – western central, northwest
Eubalaena japonica (Lacépède, 1818). North Pacific right whale	EN	Pacific – eastern central, northwest, northeast
E. japonica (Northeast Pacific Subpopulation)	CR	Pacific – northeast, eastern central
Eubalaena australis (Desmoulins, 1822). Southern right whale	LC	Atlantic – southwest, southeast, Antarctic; Indian Ocean – western, eastern, Antarctic; Pacific – southwest, southeast
Eubalaena australis (Chile-Peru Subpopulation)	CR	Pacific – southeast
Family Neobalaenidae		
Caperea marginata (Gray, 1846). Pygmy right whale	DD	Atlantic – southeast, southwest, Antarctic; Indian Ocean – western, eastern, Antarctic; Pacific – southeast, southwest

	IUCN STATUS	FAO Fishing Region
Family Eschrichtiidae		
Eschrichtius robustus (Lilljeborg, 1861). Gray whale	LC	Arctic Sea; Pacific – eastern central, northwest, northeast, western central
Eschrichtius robustus (western subpopulation)	CR	Pacific – northwest
Family Balaenopteridae		
Balaenoptera acutorostrata Lacépède, 1804. Common minke whale	LC	Arctic Sea; Atlantic – northeast, northwest, western central, eastern central, southwest, southeast; Indian Ocean – eastern, western, Antarctic; Pacific – southwest, southeast, northeast, northwest, eastern central, western central, Antarctic
Balaenoptera bonaerensis Burmeister, 1867. Antarctic minke whale	DD	Atlantic – southwest, western central, southeast; Indian Ocean – eastern, western, Antarctic; Pacific – southwest, southeast, Antarctic
Balaenoptera borealis Lesson, 1828. Sei whale	EN	Atlantic – western central, northeast, northwest, eastern central, southeast, southwest, Antarctic; Indian Ocean – eastern, western, Antarctic; Pacific – southwest, southeast, northeast, northwest, eastern central, western central, Antarctic
Balaenoptera edeni Anderson, 1879. Bryde's whale	DD	Atlantic – southeast, western central, eastern central, southwest, northwest; Indian Ocean – western, eastern; Pacific – northeast, western central, southwest, eastern central, southeast
B. edeni (Gulf of Mexico subpopulation)	CR	Atlantic – western central
Balaenoptera musculus (Linnaeus, 1758). Blue whale	EN	Arctic Sea; Atlantic – northeast, northwest, southeast, western central, eastern central, southwest, Antarctic; Indian Ocean – western, eastern, Antarctic; Pacific – southwest, southeast; northeast, northwest, eastern central, western central, Antarctic
B. m. intermedia Burmeister, 1871. Antarctic blue whale	CR	Atlantic – Antarctic; Indian Ocean – Antarctic; Pacific – Antarctic
B. m. brevicauda Ichihara, 1966. Pygmy blue whale	DD	Atlantic – southwest, southeast, Antarctic; Indian Ocean – western, eastern, Antarctic; Pacific – southwest, southeast, Antarctic

	IUCN STATUS	FAO Fishing Region
Balaenoptera omurai Wada, Oishi and Yamada, 2003. Omura’s whale	DD	Indian Ocean – eastern; Pacific – northwest, western central
Balaenoptera physalus (Linnaeus, 1758). Fin whale	EN	Arctic Sea; Atlantic – eastern central, southeast, northwest, northeast, southwest, western central, Antarctic; Indian Ocean – eastern, western, Antarctic; Mediterranean and Black Sea; Pacific – northeast, northwest, southeast, eastern central, western central, southwest, Antarctic
B. physalus (Mediterranean subpopulation)	EN	Arctic Sea; Atlantic – eastern central, southeast, northwest, northeast, southwest, western central, Antarctic; Indian Ocean – eastern, western, Antarctic; Mediterranean and Black Sea; Pacific – northeast, northwest, southeast, eastern central, western central, Antarctic, southwest
B. quoyi (Southern hempisphere subpopulation)	[not assessed]	?
Megaptera novaeangliae (Borowski, 1781). Humpback whale	LC	Arctic Sea; Atlantic – northeast, northwest, southeast, western central, eastern central, Antarctic, southwest; Indian Ocean – Antarctic, western, eastern; Pacific – southwest, southeast, northeast, Antarctic, northwest, eastern central, western central
M. novaeangliae (Arabian Sea subpopulation)	EN	Indian Ocean – western
M. novaeangliae (Oceana subpopulation)	EN	Pacific – Antarctic, southeast, southwest, western central
ODONTOCETI		
Family Physeteridae		
Physeter macrocephalus Linnaeus, 1758. Sperm whale, cachalot	VU	Atlantic – western central, northeast, northwest, southeast, eastern central, Antarctic, southwest; Indian Ocean – eastern, western, Antarctic; Mediterranean and Black Sea; Pacific – southwest, southeast, northwest, northeast, Antarctic, eastern central, western central
Physeter macrocephalus (Mediterranean subpopulation)	EN	Mediterranean and Black Sea

	IUCN STATUS	FAO Fishing Region
Family Kogiidae		
Kogia breviceps (Blainville, 1838). Pygmy sperm whale	DD	Atlantic – western central, eastern central, northeast, northwest, southeast, southwest; Indian Ocean – western, eastern; Pacific – western central, eastern central, northeast, southeast, northwest, southwest
Kogia sima (Owen, 1866). Dwarf sperm whale	DD	Atlantic – western central, eastern central, northeast, northwest, southeast, southwest; Indian Ocean – western, eastern; Pacific – western central, eastern central, northeast, southeast, northwest, southwest
Family Ziphiidae		
Berardius arnuxii Duvernoy, 1851. Arnoux's beaked whale	DD	Atlantic – southwest, southeast, Antarctic; Indian Ocean – western, Antarctic, eastern; Pacific – southwest, Antarctic, southeast
Berardius bairdii Stejneger, 1883. Baird's beaked whale	DD	Pacific – eastern central, northwest, northeast
Hyperoodon ampullatus (Forster, 1770). Northern bottlenose whale	DD	Atlantic – northeast, northwest
Hyperoodon planifrons Flower, 1882. Southern bottlenose whale	LC	Atlantic – southwest, southeast, Antarctic; Indian Ocean – western, Antarctic, eastern; Pacific – southwest, Antarctic, southeast
Indopacetus pacificus (Longman, 1926). Longman's beaked whale, tropical bottlenose whale	DD	Indian Ocean – western, eastern; Pacific – western central
Mesoplodon bidens (Sowerby, 1804). Sowerby's beaked whale	DD	Atlantic – northeast, northwest, eastern central
Mesoplodon bowdoini Andrews, 1908. Andrews' beaked whale	DD	Atlantic – southwest; Indian Ocean – eastern; Pacific – southwest
Mesoplodon carlhubbsi Moore, 1963. Hubbs' beaked whale	DD	Pacific – eastern central, northwest, northeast
Mesoplodon europaeus (Gervais, 1855). Gervais' beaked whale	DD	Atlantic – western central, northwest
Mesoplodon ginkgodens Nishiwaki and Kamiya, 1958. Ginkgo-toothed beaked whale	DD	Indian Ocean – western, eastern; Pacific – eastern central, northwest, southwest, western central
Mesoplodon grayi von Haast, 1876. Gray's beaked whale	DD	Atlantic – southeast, southwest, Antarctic; Indian Ocean – western, Antarctic, eastern; Pacific – southeast, southwest
Mesoplodon hectori (Gray, 1871). Hector's beaked whale	DD	Atlantic – southeast, southwest; Indian Ocean – eastern; Pacific – eastern central, southeast, southwest
Mesoplodon layardii (Gray, 1865). Strap-toothed beaked whale, Layard's beaked whale	DD	Atlantic – southeast, southwest, Antarctic; Indian Ocean – western, Antarctic, eastern; Pacific – southeast, southwest

	IUCN STATUS	FAO Fishing Region
Mesoplodon mirus True, 1913. True's beaked whale	DD	Atlantic – western central, northeast, northwest, southeast; Indian Ocean – eastern
Mesoplodon perrini Dalebout, Mead, Baker, Baker and van Helden, 2002. Perrin's beaked whale	DD	Pacific – northeast
Mesoplodon peruvianus Reyes, Mead and Van Waerebeek, 1991. Pygmy beaked whale	DD	Pacific – southeast
Mesoplodon stejnegeri True, 1885. Stejneger's beaked whale	DD	Pacific – eastern central, northwest, northeast
Mesoplodon traversii (Gray, 1874). Spade-toothed whale	DD	Pacific – southeast, southwest
Mesoplodon densirostris (Blainville, 1817). Blainville's beaked whale	DD	Atlantic – northeast, eastern central, southwest, southeast, northwest, western central; Indian Ocean – eastern, western; Mediterranean and Black Sea; Pacific – western central, eastern central, northwest, southwest, southeast
Tasmacetus shepherdi Oliver, 1937. Shepherd's beaked whale, Tasman beaked whale	DD	Atlantic – southwest; Indian Ocean – eastern; Pacific – southeast; Pacific – southwest
Ziphius cavirostris G. Cuvier, 1823. Cuvier's beaked whale, goose-beaked whale	LC	Atlantic – western central, northeast, eastern central, southwest, southeast, northwest; Indian Ocean – western, eastern; Mediterranean and Black Sea; Pacific – southeast, northeast, northwest, eastern central, western central, southwest
Ziphius cavirostris (Mediterranean subpopulation)	DD	Mediterranean and Black Sea
Family Platanistidae		
Platanista gangetica (Lebeck, 1801). South Asian river dolphin, Indian river dolphin	EN	[FAO areas not provided] -- Bangladesh; India; Nepal; Pakistan
P. g. gangetica (Lebeck, 1801). Susu, Ganges river dolphin	EN	[FAO areas not provided] -- Bangladesh; India; Nepal
P. g. minor Owen, 1853. Bhulan	EN	[FAO areas not provided] -- India; Pakistan
Family Iniidae		
Inia geoffrensis (Blainville, 1817). Amazon river dolphin	DD	[FAO areas not provided] -- Bolivia, Plurinational States of; Brazil; Colombia; Ecuador; Peru; Venezuela, Bolivarian Republic of
I. g. geoffrensis	[not assessed]	
I. g. boliviensis	[not assessed]	
I. g. humboldtiana	[not assessed]	

	IUCN STATUS	FAO Fishing Region
Family Lipotidae		
Lipotes vexillifer Miller, 1918. Baiji, Yangtze river dolphin – possibly extinct	CR	[FAO areas not provided] -- China
Family Pontoporiidae		
Pontoporia blainvillei (Gervais and d'Orbigny, 1844). Franciscana, toninha.	VU	Atlantic – southwest
Pontoporia blainvillei (Rio Grande Do Sul/Uruguay subpopulation)	VU	Atlantic – southwest
Family Monodontidae		
Delphinapterus leucas (Pallas, 1776). Beluga, white whale	LC	Arctic Sea; Atlantic – northwest, northeast; Pacific – northeast, northwest
Delphinapterus leucas (Cook Inlet subpopulation)	CR	Pacific – northeast
Monodon monoceros Linnaeus, 1758. Narwhal	LC	Arctic Sea; Atlantic – northwest, northeast
Family Delphinidae		
Cephalorhynchus commersonii (Lacépède, 1804). Commerson's dolphin	LC	Atlantic – southwest; Indian Ocean – Antarctic; Pacific – southeast
C. c. commersonii	[not assessed]	
C. c. kerguelenensis	[not assessed]	
Cephalorhynchus eutropia (Gray, 1846). Chilean dolphin	NT	Pacific – southeast
Cephalorhynchus heavisidii (Gray, 1828). Heaviside's dolphin, Haviside's dolphin	DD	Atlantic – southeast
Cephalorhynchus hectori (Van Bénéden, 1881). Hector's dolphin	EN	Pacific – southwest
C. h. maui A. Baker, Smith and Pichler, 2002. Maui's dolphin, North Island Hector's dolphin	CR	Pacific – southwest
Delphinus capensis Gray, 1828 Long-beaked common dolphin	DD	Atlantic – southwest, southeast, northwest, northeast, western central, eastern central; Indian Ocean – eastern, western; Pacific – southwest, northwest, eastern central, western central, southeast

	IUCN STATUS	FAO Fishing Region
Delphinus delphis Linnaeus, 1758. Common dolphin, saddleback dolphin	LC	Atlantic – northeast, eastern central, southwest, southeast, northwest, western central; Indian Ocean – eastern, western; Mediterranean and Black Sea; Pacific – western central, eastern central, northwest, southwest, southeast
D. delphis (Mediterranean subpopulation)	EN	Mediterranean and Black Sea
D. d. ponticus Barabash, 1935. Black Sea common dolphin	VU	Mediterranean and Black Sea
Feresa attenuata Gray, 1874. Pygmy killer whale	DD	Atlantic – southeast, western central, eastern central, southwest; Indian Ocean – western, eastern; Pacific – northwest, western central, southwest, eastern central, southeast
Globicephala macrorhynchus Gray, 1846. Short-finned pilot whale	DD	Atlantic – western central, northeast, eastern central, southwest, southeast, northwest; Indian Ocean – western, eastern; Mediterranean and Black Sea; Pacific – southeast, northeast, northwest, eastern central, western central, southwest
Globicephala melas (Traill, 1809). Long-finned pilot whale	DD	Atlantic – southwest, southeast, western central, eastern central, Antarctic, northeast, northwest; Indian Ocean – eastern, western, Antarctic; Mediterranean and Black Sea; Pacific – southwest, southeast
G. melas (Mediterranean subpopulation)	DD	Mediterranean and Black Sea
Grampus griseus (G. Cuvier, 1812). Risso's dolphin, grampus	LC	Atlantic – western central, southwest, eastern central, northeast, northwest, southeast; Indian Ocean – western, eastern; Mediterranean and Black Sea; Pacific – southwest, western central, northeast, eastern central, northwest, southeast
Grampus griseus (Mediterranean subpopulation)	DD	Mediterranean and Black Sea
Lagenodelphis hosei Fraser, 1956. Fraser's dolphin	LC	Atlantic – western central, southwest, southeast, eastern central; Indian Ocean – eastern, western; Pacific – northwest, eastern central, western central, southeast
Lagenorhynchus acutus (Gray, 1828). Atlantic white-sided dolphin	LC	Atlantic – northeast, northwest
Lagenorhynchus albirostris (Gray, 1846). White-beaked dolphin	LC	Atlantic – northwest, northeast
Lagenorhynchus australis (Peale, 1848). Peale's dolphin	DD	Atlantic – southwest; Pacific – southeast
Lagenorhynchus cruciger (Quoy and Gaimard, 1824). Hourglass dolphin	LC	Atlantic – southeast, Antarctic, southwest; Indian Ocean – Antarctic, eastern; Pacific – southwest, Antarctic, southeast
Lagenorhynchus obliquidens Gill, 1865. Pacific white-sided dolphin	LC	Pacific – northwest, northeast, eastern central

	IUCN STATUS	FAO Fishing Region
Lagenorhynchus obscurus (Gray, 1828). Dusky dolphin	DD	Atlantic – southeast, southwest; Pacific – southeast, southwest
Lagenorhynchus o. obscurus	[not assessed]	
Lagenorhynchus o. fitzroyi	[not assessed]	
Lagenorhynchus o. ssp.	[not assessed]	
Lissodelphis borealis (Peale, 1848). Northern right-whale dolphin	LC	Pacific – northwest, northeast, eastern central
Lissodelphis peronii (Lacépède, 1804). Southern right-whale dolphin	DD	Atlantic – Antarctic, southwest, southeast; Indian Ocean – Antarctic, western, eastern; Pacific – Antarctic, southwest, southeast
Orcaella brevirostris (Owen in Gray, 1866). Irrawaddy dolphin, pesut	EN	Indian Ocean – eastern; Pacific – western central
Orcaella brevirostris (Ayeyarwady River subpopulation)	CR	[FAO areas not provided] -- Myanmar
Orcaella brevirostris (Mahakam River subpopulation)	CR	Pacific – western central
Orcaella brevirostris (Malampaya Sound subpopulation)	CR	Pacific – western central
Orcaella brevirostris (Mekong River subpopulation)	CR	[FAO areas not provided] -- Cambodia; Lao People's Democratic Republic; Viet Nam
Orcaella brevirostris (Songkhla Lake subpopulation)	CR	[FAO areas not provided] -- Thailand
Orcaella heinsohni Beasley, Robertson and Arnold, 2005. Australian snubfin dolphin	VU	Indian Ocean – eastern; Pacific – western central
Orcinus orca (Linnaeus, 1758). Killer whale, orca	DD	Arctic Sea; Atlantic – southeast, northeast, eastern central, northwest, Antarctic, western central, southwest; Indian Ocean – western, eastern, Antarctic; Mediterranean and Black Sea; Pacific – northwest, southeast, northeast, southwest, eastern central, western central, Antarctic
Peponocephala electra (Gray, 1846). Melon-headed whale, Electra dolphin	LC	Atlantic – southeast, western central, eastern central, southwest, northwest; Indian Ocean – western, eastern; Pacific – northwest, western central, southwest, eastern central, southeast
Pseudorca crassidens (Owen, 1846). False killer whale	DD	Atlantic – southeast, western central, eastern central, southwest, northwest; Indian Ocean – western, eastern; Pacific – northwest, western central, southwest, eastern central, southeast
Sousa teuszii (Kükenthal, 1892). Atlantic humpback dolphin	CR	Atlantic – eastern central, southeast
Sousa chinensis (Osbeck, 1765). Indo-Pacific humpback dolphin	VU	Indian Ocean – eastern; Pacific – western central
S. c. chinensis	[not assessed]	

	IUCN STATUS	FAO Fishing Region
S. c. taiwanensis Wang, Yang and Hung, 2015. Taiwanese humpback dolphin	CR	Pacific – northwest
Sousa plumbea (G. Cuvier, 1829). Indian Ocean humpback dolphin	EN	Atlantic – southeast; Indian Ocean – western, eastern
Sousa sahulensis Jefferson and Rosenbaum, 2014. Australian humpback dolphin, Sahul dolphin	VU	Indian Ocean – eastern; Pacific – western central
Sotalia fluviatilis (Gervais and Deville in Gervais, 1853). Tucuxi	DD	[FAO areas not provided] -- Brazil; Colombia; Ecuador; Peru
Sotalia guianensis (Van Bénedén, 1864). Guiana dolphin, costero	DD	Atlantic – western central, southwest
Stenella attenuata (Gray, 1846). Pantropical spotted dolphin	LC	Atlantic – western central, southwest, southeast, northwest, eastern central; Indian Ocean – eastern, western; Pacific – southeast, northwest, eastern central, western central, southwest
S. a. attenuatta	[not assessed]	
S. a. graffmani	[not assessed]	
Stenella clymene (Gray, 1850). Clymene dolphin	DD	Atlantic – western central, southwest, southeast, northwest, eastern central
Stenella coeruleoalba (Meyen, 1833). Striped dolphin	LC	Atlantic – western central, northeast, eastern central, southwest, southeast, northwest; Indian Ocean – western, eastern; Mediterranean and Black Sea; Pacific – southeast, northeast, northwest, eastern central, western central, southwest
Stenella coeruleoalba (Mediterranean subpopulation)	VU	Mediterranean and Black Sea
Stenella frontalis (G. Cuvier, 1829). Atlantic spotted dolphin	DD	Atlantic – western central, southwest, southeast, northwest, northeast, eastern central
Stenella longirostris (Gray, 1828). Spinner dolphin	DD	Atlantic – western central, southwest, southeast, northwest, eastern central; Indian Ocean – eastern, western; Pacific – southeast, northwest, eastern central, western central, southwest
S. l. orientalis Perrin, 1990. Eastern spinner dolphin	VU	Pacific – eastern central
S. l. longirostris	[not assessed]	
S. l. centroamericana	[not assessed]	
S. l. roseiventris	[not assessed]	

	IUCN STATUS	FAO Fishing Region
Steno bredanensis (G. Cuvier in Lesson, 1828). Rough-toothed dolphin	LC	Atlantic – western central, eastern central, northeast, southeast, southwest; Indian Ocean – western, eastern; Mediterranean and Black Sea; Pacific – southwest, western central, northeast, eastern central, northwest, southeast
Tursiops aduncus (Ehrenberg, 1833). Indo-Pacific bottlenose dolphin	DD	Indian Ocean – western, eastern; Pacific – western central, northwest
Tursiops truncatus (Montagu, 1821). Common bottlenose dolphin	LC	Atlantic – western central, southwest, eastern central, northeast, northwest, southeast; Indian Ocean – western, eastern; Mediterranean and Black Sea; Pacific – southwest, western central, northeast, eastern central, northwest, southeast
T. t. ponticus Barabash-Nikiforov, 1940. Black Sea bottlenose dolphin	EN	Mediterranean and Black Sea
Tursiops truncatus (Fjordland subpopulation)	CR	Pacific – southwest
Tursiops truncatus (Mediterranean subpopulation)	VU	Mediterranean and Black Sea
Family Phocoenidae		
Neophocaena phocaenoides (G. Cuvier, 1829). Indo-Pacific finless porpoise	VU	Indian Ocean – western, eastern; Pacific – northwest, western central
Neophocaena asiaeorientalis (Pilleri and Gihr, 1972). Narrow-ridged finless porpoise	EN	Pacific – northwest
N. a. asiaeorientalis (Pilleri and Gihr, 1972). Yangtze finless porpoise	CR	[FAO areas not provided] -- China (Anhui, Hubei, Jiangsu, Shanghai)
N. a. sunameri Pilleri and Gihr, 1975. East Asian finless porpoise, sunameri	[not assessed]	
Phocoena dioptrica Lahille, 1912. Spectacled porpoise	DD	Atlantic – southwest, Antarctic; Indian Ocean – Antarctic, eastern; Pacific – southeast, southwest
Phocoena phocoena (Linnaeus, 1758). Harbor porpoise	LC	Arctic Sea; Atlantic – eastern central, northeast, northwest; Mediterranean and Black Sea; Pacific – eastern central, northwest, northeast
P. p. phocoena (Linnaeus, 1758). Atlantic harbor porpoise	[not assessed]	
P. p. vomerina (Gill, 1865). Eastern Pacific harbor porpoise	[not assessed]	
P. p. relicta Abel, 1905. Black Sea harbor porpoise	EN	Mediterranean and Black Sea
P. p. un-named subsp. Western Pacific harbor porpoise	[not assessed]	

	IUCN STATUS	FAO Fishing Region
Phocoena sinus Norris and McFarland, 1958. Vaquita, Gulf of California harbor porpoise	CR	Pacific – eastern central
Phocoena spinipinnis Burmeister, 1865. Burmeister's porpoise	DD	Atlantic – southwest; Pacific – southeast
Phocoenoides dalli (True, 1885). Dall's porpoise, Dall porpoise	LC	Pacific – northwest, northeast, eastern central
ORDER Sirenia		
Family Trichechidae		
Trichechus inunguis (Natterer, 1883). Amazonian manatee	VU	[FAO areas not provided] -- Brazil; Colombia; Ecuador; Peru
Trichechus manatus Linnaeus, 1758. West Indian manatee	VU	Atlantic – western central, northwest, southwest
T. m. latirostris (Harlan, 1824). Florida manatee	EN	Atlantic – western central
T. m. manatus Linnaeus, 1758. Antillean manatee	EN	Atlantic – western central, southwest
Trichechus senegalensis Link, 1795. West African manatee, African manatee	VU	Atlantic – southeast, eastern central
Family Dugongidae		
Dugong dugon (Müller, 1776). Dugong	VU	Indian Ocean – eastern, western; Pacific – northwest, western central
Hydrodamalis gigas (Zimmerman, 1780). Steller's sea cow – extinct	EX	[FAO areas not provided] -- Russian Federation; United States

APPENDIX 3B

Policy instruments applicable to marine mammal bycatch

International law, laid out in the United Nations Convention on the Law of the Sea (1982), identifies rights and obligations of States and gives an international basis for pursuing the protection and sustainable development of the marine and coastal environment and its resources. Of the approaches presented, "sustainable use and conservation of marine living resources of the high seas…[and] under national jurisdiction", "strengthening international, including regional, cooperation and coordination" apply to marine mammals and their management (U.N. 1992).

One international agreement under the U.N. Law of the Sea Convention is the Agreement Related to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (2011). Fifty-nine States and entities signed on to conserve straddling and highly migratory fish stocks and ensure their sustainable use (U.N. 2011). Obligations for signatory parties include assessing, monitoring, managing, protecting, and conserving resources, as well as minimizing bycatch and waste through means including selective fishing gear and techniques.

The June 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro set the stage for States to commit to many of the measures and protections regarding bycatch species (U.N. 1992). One specific outcome was agreement on promoting the use and development of selective fishing gear and fishing methods that minimize bycatch of non-target species and waste of target species.

The Convention of Biological Diversity (December 1993) is also rooted in the document adopted at the UNCED. It aims to conserve biological diversity, promote sustainable use of natural resources, and share the benefits fairly and equitably that stem from using genetic resources (CBD 2018). Non-target bycatch species in fisheries that are vulnerable, endangered, or threatened with extinction fall under this agreement as well. Although bycatch is not called out specifically as a threat, species that are endangered and threatened from human activities like fishing put biological diversity at risk.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is an international agreement between governments in which members voluntarily commit to measures that can ensure that international trade in wild animals and plants does not threaten their survival (CITES 2018). This is a legally binding agreement but does not replace national laws, instead it provides a framework for each member to develop its own legislation. Over forty marine mammal species are listed under Appendix I (species threatened with extinction) and many more are listed under Appendix II (species for which trade must be controlled to maintain their populations).

The Convention on the Conservation of Migratory Species of Wild Animals (CMS), an environmental treaty under the United Nations' Environment Programme from 1991, provides a legal framework to internationally coordinate conservation measures throughout a migratory species' range (CMS 2018). Appendix I of the CMS lists migratory species threatened with extinction. Entities try to protect these species, conserve or restore their habitats, and mitigate migration and other obstacles that cause risk. Appendix II lists migratory species that may need or would benefit from international cooperative measures. The CMS strongly encourages entities to work together through international agreements to conserve these species and their habitats. To date, three agreements and four memoranda of understanding have been created in relation to marine mammals under this framework.

The Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish, and North Seas is one such international agreement. It strives to maintain populations of small cetaceans (20 species) in the agreement area (ASCOBANS 2018). The agreement came into play in 1994 and the area was expanded in 2008, with the addition of the North East Atlantic and Irish Seas. Entanglement in fishing gear is considered the greatest threat to these species in the agreement area.

Another such international agreement stemming from CMS is the Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area. It aims to cooperatively reduce threats to cetaceans by improving knowledge about them.

The Trilateral Wadden Seal Agreement between Denmark, Germany, and the Netherlands has been in effect since 1991. This agreement focuses on research and monitoring, takes, habitat protection, and raising awareness of Wadden Sea seal species.

The Memorandum of Understanding on the Conservation and Management of Dugongs *(Dugong dugon)* and their Habitats throughout their Range was created to ensure the long-term survival of dugongs and their sea grass habitats throughout their range. Similarly, the focus of the Memorandum of Understanding concerning the Conservation of the Manatee and Small Cetaceans of Western Africa and Macaronesia (2008) is to provide a platform to implement research and conservation for the 32 species are listed. The Memorandum of Understanding concerning Conservation Measures for the Eastern Atlantic Populations of the Mediterranean Monk Seal *(Monachus monachus)* (2007) also aims to improve the conservation status and habitats for monk seals in the Eastern Atlantic, where entanglement in fishing gear remains a significant threat to this critically endangered species. The Memorandum of Understanding for the Conservation of Cetaceans and their Habitats in the Pacific Islands Region (2006) covers cooperative conservation of 48 species in this region.

The United Nations' Food and Agricultural Organization's (FAO) Code of Conduct for Responsible Fisheries (October 1995) requires that member states conduct fishing with due regard for the environment (FAO 1995). With regards to bycatch, it states that members should, in order to assess the status of fisheries, collect reliable and accurate data, including data on bycatch, discards, and waste. The Code is the FAO's voluntary guidelines for managing and developing commercial fisheries while achieving conservation objectives. It requires protection of endangered species through adoption of appropriate scientific evidence-based measures. Although the Code was endorsed by all members, by 2009, when development of the FAO's International Guidelines on Bycatch Management and Reduction of Discards (February 2011) began, concern that bycatch and discards were elevating fishing mortality to levels beyond sustainable levels and threatening biodiversity and food security as well as livelihoods, spurred further action.

The international bycatch guidelines' purpose was to help members implement an ecosystem approach to fisheries management by effectively reducing discards and controlling bycatch levels (FAO 2011). These guidelines aimed to minimize capture and mortality of species not used in "a manner consistent with the Code"; provide guidance on measures that promote effective management of bycatch and reduce discards; and improve reporting and accounting of all components of catch, including bycatch and discards. These guidelines identify endangered, threatened, and protected species as a bycatch problem. According to the guidelines, members should assess fisheries, identifying any endangered and protected species bycatch. States should also be able to identify where bycatch species may overlap with fishing operations through use of seabed maps, and/or species distributions and ranges, particularly those of "rare, endangered, threatened or protected species" (p. 12). Further, in order to reduce interactions with these types of species, states should identify and establish areas where use of all or some fishing gears is limited or prohibited, using the best available scientific information.

The Convention on the Conservation of Antarctic Marine Living Resources (CAMLR) was adopted in 1980. The Convention is an international treaty developed to prevent krill being removed at a rate that is detrimental to the ecosystems for which it is a food source, particularly the seabirds, seals, whales, and fish (CCAMLR 2014).

The UN High Seas Bycatch and Driftnet Resolutions, UN General Assembly Resolutions on Large-scale Pelagic Drift-net Fishing also encourages parties to develop selective gears and techniques to reduce bycatch and waste.

The Agreement on the International Dolphin Conservation Program (AIDCP) was developed to reduce incidental mortalities of dolphins in the tuna purse seine fishery in the Eastern Pacific Ocean (IATTC 2018). It became legally binding in 1999, and succeeded the 1992 Agreement on the Conservation of Dolphins.

APPENDIX 4

Summary table of bycatch mitigation techniques

This table was created by participants at the 2018 FAO *Expert Workshop on Means and Methods for Reducing Marine Mammal Mortality in Fishing and Aquaculture Operations*. For *Behaviour*, active attraction indicates that marine mammals are drawn to fishing operations because of an opportunity to feed on bait or target catch (depredation). *Gear* follows FAO's fishing gear classification but generally avoids using subcategories (*e.g.*, driftnets versus bottom-set gillnets). *Techniques* use the same names referred to in the Background Paper but may include additional explanatory labels. *Bycatch* and *Target Catch* species listed are ones indicated in the associated references, and include information on the effect on target catch when reported. *Evidence to Support or Refute Efficacy* is given a "Y" if one or more evaluations of the technique provided convincing evidence that the technique can reduce bycatch or interactions, whereas a "N" indicates either that this evidence is lacking or generally has been shown to be ineffective. Some techniques are not included in the table even though they are mentioned in the Background Paper, particularly if there is almost no information on them or they are unlikely to be tested or used (e.g., whale-free buoy, noxious bait). Seeing as a huge body of work exists on acoustic deterrents and gillnets, much of this information was summarized from a review paper by Dawson et al. (2013). Time-area closures and gear switching studies were listed in the Background Paper but not in this table. In keeping with the focus of the workshop and the widespread preference for bycatch prevention over post-hooking or post entanglement release by direct intervention, these latter methods were excluded from the table. If the group concluded that additional trials are recommended, a "Y" was entered in the relevant column, or a "N" if not. Recommendations for additional trials may indicate the need to address additional research questions based on the experience in testing or using particular techniques, for example optimal deployment configuration of acoustic deterrents, or at a broader level indicate the need for greater proof-of-concept with encouraging ideas. In general, the group acknowledged that even minor adjustments to the dimensions, specifications, or deployment of devices, including fishing operational changes, can make a major difference in their efficacy. An important first step in using particular techniques should be to evaluate them within the local fishery, recognizing likely differences in local marine mammal populations and fishing practices. Participants further noted that the scientific rigor varies among published trials, and thus an attempt was made to factor in that perspective into the determination of efficacy and whether or not further trials were warranted. Only trials involving marine species are covered. For more thorough treatment of these techniques, the reader should consult the Background Paper that also includes the citations in the table. Summaries for trawl fisheries were aided by a paper currently in review by Hamilton and Baker (2018, Suppl. Tables).

SPECIES GROUP	BEHAVIOUR	GEAR	TECHNIQUE	REF.	BYCATCH SPECIES	TARGET CATCH	EVIDENCE TO SUPPORT (Y) OR REFUTE (N) EFFICACY?	ADDITIONAL TRIALS RECOMMENDED?	NOTES
Small cetaceans - odontocetes	Random encounter	Gillnets	Acoustic deterrents (pingers)	Dawson et al. 2013	Harbour porpoise (*Phocoena phocoena*)	Multiple species as part of fisheries trials - target catches generally vary little between pingered and unpingered nets	Y	Y	Despite some variability in results across many trials, most of the experimental evidence shows that pingers create an area displacement effect that leads to reduced bycatch.
Small cetaceans - odontocetes	Random encounter	Gillnets	Acoustic deterrents (pingers)	Dawson et al. 2013	Common dolphin (*Delphinus delphis*)	Multiple species	Y	Y	Significant bycatch reduction in at least one fishery, however behavioral studies show variable results.
Small cetaceans - odontocetes	Random encounter	Gillnets	Acoustic deterrents (pingers)	Dawson et al. 2013	Striped dolphin (*Stenella coeruleoalba*)	Multiple species	?	Y	Only based on one study with a small sample size, so effect on this species is uncertain.
Small cetaceans - odontocetes	Random encounter?	Gillnets	Acoustic deterrents (pingers)	Dawson et al. 2013	Indo-Pacific humpback dolphin (*Sousa chinensis*); Tucuxi (*Sotalia fluviatilis*); Hector's dolphin (*Cephalorhynchus hectori*)	Multiple species	N	Y	
Small cetaceans - odontocetes	Random encounter?	Gillnets	Acoustic deterrents (pingers)	Dawson et al. 2013	Burmeister's porpoise (*Phocoena spinipinnis*); Dusky dolphin (*Lagenorhynchus obscurus*)	Multiple species	?	Y	
Small cetaceans - odontocetes	Random encounter	Gillnets, includin g shark nets	Acoustic deterrents (pingers)	Soto et al. 2013	Australian snubfin dolphin (*Orcaella heinsohni*); Indo-Pacific humpback dolphin (*Sousa chinensis*)	Multiple species	N	Y	Slight behavioral changes noted in the presence of pingers, but no area displacement
Small cetaceans - odontocetes	Random encounter	Gillnets	Acoustic deterrents (pingers)	Barlow and Cameron 2003	Common dolphin (*Delphinus delphis*)	Swordfish (*Xiphias gladius*) and thresher shark (*Alopias vulpinus*) - no significant difference in catch rates	Y	Y	Reduced bycatch

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Pinnipeds	Active attraction	Gillnets	Acoustic deterrents (pingers)	Barlow and Cameron 2003	California sea lion (*Zalophus californianus*)	Swordfish (*Xiphias gladius*) and thresher shark (*Alopias vulpinus*) - no significant difference in catch rates	Y	N	Results indicated pingers reduced interactions with sea lions however an opposite result was obtained using longer term observer data in the same fishery (Carretta and Barlow 2011)
Medium cetaceans - odontocetes	Random encounter	Gillnets	Acoustic deterrents (pingers)	Carretta and Barlow 2011	Beaked whales; Pacific white-sided dolphin *Lagenorhynchus obliquidens*); Northern right whale dolphin (*Lissodelphis borealis*)	Swordfish (*Xiphias gladius*) and thresher shark (*Alopias vulpinus*)	Y	Y	No bycatch of beaked whales over multi-year monitoring of bycatch in drift gillnets. No difference in bycatch for other two species, but sample sizes low.
Pinnipeds	Active attraction	Gillnets	Acoustic deterrents (pingers)	Carretta and Barlow 2011	California sea lion (*Zalophus californianus*); Northern elephant seal (*Mirounga angustirostris*)	Swordfish (*Xiphias gladius*) and thresher shark (*Alopias vulpinus*)	Y	N	Sea lion catch higher in pingered nets (using 10kHz pingers), possibly explained by "dinner bell" effect or some other variable. No difference for elephant seal.
Small cetaceans - odontocetes	Active attraction	Gillnets	Acoustic deterrents (pingers)	Dawson et al. 2013	Bottlenose dolphin (*Tursiops truncatus*)	Multiple species	N	N	Bycatch of bottlenose dolphins have sometimes been shown to increase in nets with pingers compared to control nets. This method highlights the inadvisable use of pingers when cetaceans are actively attracted to fishing gear.
Small cetaceans - odontocetes	Random encounter	Gillnets	Acoustic deterrents (pingers)	A. Bjorge, *in progress*	Harbour porpoise (*Phocoena phocoena*); Harbour seal (*Phoca vitulina*)	Cod (*Gadus morhua*) - more was caught with pingers; Monkfish (*Lophius piscatorius*) - less was caught with pingers	Y	Y	Preliminary results: Some (~30%) reduction in porpoise bycatch that will get it below PBR; Seal bycatch increased
Small cetaceans - odontocetes	Random encounter	Gillnets	Acoustic deterrents (pingers)	H. Einarsson, *pers. comm.*	Harbour porpoise (*Phocoena phocoena)*	Cod (*Gadus morhua*) - fewer caught	Y	Y	
Small cetaceans - odontocetes	Random encounter	Gillnets	Acoustic deterrents (pingers)	Mangel 2013	Burmeister's porpoise (*Phocoena spinipinnis*); Dusky dolphin (*Lagenorhynchus obscurus*); Bottlenose dolphin (*Tursiops truncatus*);	Sharks and rays - no difference	?	Y	Effect reported as statistically significant for all species pooled with < 50% reduction; some difference in net dimensions and soak time between control and treatments. No statistically significant differences in bycatch when species considered individually.

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					Globicephala spp.); Common dolphin (*Delphinus* spp.)				
Small cetaceans - odontocetes	Random encounter	Gillnets	Acoustic deterrents (pingers)	Amir 2010	Bottlenose dolphin (*Tursiops truncatus*); Spinner dolphin (*Stenella longirostris*); Indian Ocean humpback dolphin (*Sousa plumbea*)	Large pelagics	?	Y	Small sample sizes
Small cetaceans - odontocetes	Random encounter	Gillnet - drift	Acoustic deterrents - Glass bottle alarms or plastic bottle acoustic reflectors	P. Berggren, *pers. comm.*	Bottlenose dolphin (*Tursiops truncatus*); Spinner dolphin (*Stenella longirostris*)	Large pelagics - no effect in small-scale trial	N	Y	A trial undertaken in Zanzibar did not produce data on dolphin bycatch
Small cetaceans - odontocetes; pinnipeds	Random encounter (porpoise)/Active attraction (pinnipeds)	Gillnets	Acoustic deterrents (pingers)	Bordino et al. 2002	Franciscana dolphin (*Pontoporia blainvillei*); Burmeister's porpoise (*Phocoena spinipinnis*)	Demersal fishes	Y	N - with 10kHz pingers owing to increase in pinniped depredation	Significant reduction of Franciscana bycatch in a fishery trial; Burmeister's poprpoise only caught in unpingered nets, but sample size was small. Increase in South American sea lion (*Otaria byronia*) interactions in pingered nets
Small cetaceans - odontocetes; pinnipeds	Random encounter (porpoise)/Active attraction (pinnipeds)	Gillnets	Acoustic deterrents (pingers)	Bordino et al. 2004	Franciscana dolphin (*Pontoporia blainvillei*)	Demersal fishes - similar catch-per-unit-effort between control and pingered nets	Y	N	Significant reduction in bycatch of franciscana but no difference in South American sea lion (*Otaria bryonia*) catch, perhaps because the pinger frequency was 70kHz rather than 10kHz
Small cetaceans - odontocetes	Random encounter	Gillnets	Barium sulfate nets	Trippel et al. 2003	Harbour porpoise (*Phocoena phocoena*)	Similar catches of cod *(Gadus morhua)*, pollock *(Pollachius virens)*, haddock *(Melanogrammus aeglejinus)*, and spiny dogfish *(Squalus acanthias)*	Y	N	Results may have as much to do with lower net profile or increased twine stiffness than acoustic reflectivity.

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Small cetaceans - odontocetes; pinnipeds	Random encounter (porpoise)/Active attraction (pinnipeds)	Gillnets	Barium sulfate nets	Northridge et al. 2003	Harbour porpoise (*Phocoena phocoena*); seals		N	N	Higher bycatch of both porpoise and seals. Mesh size and rigged height between control and experimental nets different, making it difficult to elucidate which factors most contributed to the observed bycatch rates.
Small cetaceans - odontocetes	Random encounter	Gillnets	Metal oxide nets	Larsen et al. 2007	Harbour porpoise (*Phocoena phocoena*)	Cod *(Gadus morhua)* - lower CPUE in iron oxide net	Y	N	Reduced bycatch
Small cetaceans - odontocetes	Random encounter	Gillnets	Barium sulfate nets	Trippel et al. 2009	Harbour porpoise (*Phocoena phocoena*)	A significant reduction in CPUE of haddock (*Melanogrammus aeglefinus*) but not for cod (*Gadus morhua*), pollock (*Pollachius virens)*, and piny dogfish (*Squalus acanthias*)	Y	N	Inconsistent results between years
Small cetaceans - odontocetes	Random encounter	Gillnets	Barium sulfate and stiffer nylon nets	Bordino et al. 2013	Franciscana dolphin (*Pontoporia blainvillei*)	Demersal fishes - similar catch-per-unit-effort between control and treatment nets	N	N	Reduction in bycatch may have to with lower net profile
Small cetaceans - odontocetes	Random encounter	Gillnets	Vertical profile of gillnets (tie downs)	Fox et al. 2011	Common dolphin (*Delphinus delphis*)	Monkfish (*Lophius americanus*)	?	Y	Small sample size; no common dolphins caught in nets with tie downs, six in nets without tie downs
Small cetaceans - odontocetes	Random encounter	Gillnets	Vertical profile of gillnets (tie downs)	Palka 2000	Harbour porpoise (*Phocoena phocoena*)	Multiple species	Y	Y	Lower bycatch in nets with tie downs
Small cetaceans - odontocetes	Random encounter	Gillnets	Low profile (drift)net	U. Shahid, *pers. comm.*	Delphinids	Tuna	Y	Y	Net 1.5-2m below ocean surface; bycatch reduced from 12,000 to 480 per year
Small cetaceans - odontocetes	Random encounter	Gillnets	Decreased soak time	H. Einarsson, *pers. comm.*	Harbour porpoise (*Phocoena phocoena*)	Cod (*Gadus morhua*)	?	Y	Fishermen have voluntarily shortened soak time, in a fishery with a high catch rate in order to increase fish quality. Some decline in porpoise catch rates but the degree to which this is an effect of population size unclear
Sirenians	Random encounter	Gillnets	Acoustic deterrents (pingers)	Hodgson et al. 2007	Dugong (*Dugong dugon*)	Multiple species	N	N	No behavioural change observed between an array simulating net deployments observed when pingers on or off

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Small cetaceans - odontocetes	Active attraction	Pots	Trap (pot) guards/net modification	Noke and Odel 2002	Bottlenose dolphin (*Tursiops truncatus*)	Blue crab (*Callinectes sapidus*)	Y	Y	Eliminated interactions by better securing the bait bag
Mysticetes	Random encounter	Pots	Grappling	Pemaquid Fishermen's Co-Op 2012	All mysticetes	Lobster (*Homarus americanus*)	Y	Y	Removal of vertical lines prevents entanglement risk in those ropes
Mysticetes	Random encounter	Pots	Ropeless fishing	DeAlteris 1999; Hopkins and Hoggard 2006; Allen and DeAlteris 2007	All mysticetes	Lobster, Crab, Slime eel, Whelk (Florida to e. Canada)	Y	Y	Removal of vertical lines prevents entanglement risk in those ropes
Mysticetes	Random encounter	Pots	Visual deterrents - different colored ropes	Kraus et al. 2014	North Atlantic right whale (*Eubalaena glacialis*)	Lobster, Crab, Slime eel, and Whelk pots, and gillnet buoy lines (Florida to e. Canada)	Y	Y	In a behavioral trial, red and orange rope mimics were detectable near the surface during daylight hours at nearly twice the distance than for green ropes, a finding that was statistically significant. In that same experiment, black ropes were detectable at distances greater than green, but less than red/orange, with the difference between black and red/orange not significant.
Mysticetes	Random encounter	Pots and gillnets - ropes	Visual deterrents - different colored ropes	Kot et al. 2012	Minke whale (*Balaenoptera acutorostrata*)	Simulated array	?	Y	Minke whales exhibited statistically significant behavioral responses to white and black ropes in a nearshore habitat, however the behavioral changes occurred at distances approaching 100m which is likely beyond their visual range.
Mysticetes	Random encounter	Pots and gillnets - ropes	Gear with reduced breaking strength	Knowlton et al. 2016	North Atlantic right (*Eubalaena glacialis*), Humpback (*Megaptera novaeangliae*), Minke (*Balaenoptera acutorostrata*), and Fin (*Balaenoptera physalus*) whales	Lobster, Crab, Slime eel, and Whelk pots, and gillnet buoy lines (Florida to e. Canada)	Y	Y	Study of fishing gear retrieved from disentangled or deceased whales together with information (where available) on life history, gender, scarring, and entanglement duration showed lethal and severe entanglements more likely to occur in ropes of higher breaking strengths, especially for N.A. right whales
Mysticetes	Random encounter	Pots	Minimise ratio of vertical lines to units of fishing gear	Kite-Powell, *unpub.*		Lobster, Crab, Slime eel, Whelk (Florida to e. Canada)	Y	Y	Modelling study indicates that reducing the amount of vertical line would reduce encounter probability

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Mustellids	Active attraction	Pots	Trap (pot) guards/net modification - smaller aperture of entry	Hatfield et al. 2011	Sea otter (*Enhydra lutris*)	US west coast traps for shellfish - no reduction of Dungeness crab (*Cancer magister*)	Y	Y	Reduced entry of some otters
Sirenians	Random encounter	Pots and gillnets	Acoustic deterrents (pingers)	Bowles et al. 2001	West Indian manatee (*Trichechus manatus*)	Tank trials of captive animals	N	N	Study on captive manatees only; no sustained reaction to pingers
Mysticetes	Random encounter	Pots (ropes), gillnets	Acoustic deterrents (pingers)	Harcourt et al. 2014; Pirotta et al. 2016	Humpback whale (*Megaptera novaeangliae*)	Behavioral trial	N	N	No measurable avoidance response
Mysticetes	Random encounter	Herring weir	Acoustic deterrents (pingers)	Lien et al. 1992	Humpback whale (*Megaptera novaeangliae*)	Herring	?	N	Reduced collision and entanglement rates
Pinnipeds	Active attraction	Trap net	Trap (pot) guards/net modification - seal exclusion device, strong net and added tension, extra net layer	Suuronen 2006	Grey seal (*Halichoerus grypus*)	Salmon *(Salmo salar),* Whitefish *(Coregonus lavaratus)*	Y	Y	In combination, these modifications performed best at excluding seals
Pinnipeds	Active attraction	Trap net	Trap (pot) guards/net modification - seal exclusion device	Königson et al. 2015	Grey seal (*Halichoerus grypus*); Harbour seal (*Phoca vitulina*)	Cod (*Gadus morhua*) - comparable catch between control and experimental traps but with seasonal variability	Y	Y	
Pinnipeds	Active attraction	Trap - bagnet	Acoustic deterrents (harassment device)	Harris et al., 2014	Grey seal (*Halichoerus grypus*); Harbour seal (*Phoca vitulina*)	Salmon - higher fish landings in experimental trap	Y	Y	
Pinnipeds	Active attraction	Gillnets, traps	Acoustic deterrents (harassment device)	Geiger and Jeffries, 1987; Gearin et al., 1988; Fjällinga et al., 2006	Harbor seal *(Phoca vitulina*); grey seals (*Halichoerus grypus*); and California sea lion (*Zalophus californianus*)	Multiple species	N - habituation over time	N	Habituation and a risk of potential physical/health consequences to pinnipeds from exposure
Pinnipeds and small cetaceans - odontocetes	Active attraction	Fish farm	Acoustic deterrents (harassment device)	Götz and Janik 2014	Harbour seal (*Phoca vitulina*); harbour porpoise (*Phocoena phocoena*)	Salmon	Y	Y	Device scared harbour seals away over a two-month trial period but not harbour porpoise

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Large cetaceans - odontocetes	Active attraction	Longline	Acoustic deterrents (Passive acoustic methods)	O'Connell et al. 2015	Sperm whale (*Physeter macrocephalus*)	Sablefish (*Anoplopoma fimbria*)	N	N	No statistical significant difference between beaded and unbeaded gear
Medium cetaceans - odontocetes	Active attraction	Longline	Gear with reduced breaking strength - weaker hooks	Bayse and Kerstetter, 2010; Bigelow et al. 2012; McLellan et al. 2015	Pilot whales (*Globicephala* spp.); False killer whale (*Pseudorca crassidens*)	Tuna and swordfish - comparable CPUE	Y	Y	No statistical reduction in bycatch rates (including both serious injury and mortality) but there were observations of straightened hooks. Lab study indicated reduction in soft (lip) tissue with weak hooks and less serious hooking. Future at-sea trials would benefit from information on post-release survival and any differences in size classes of target catch. Technique does not reduce depredation. The US False Killer Whale Take Reduction Team specifies a hook diameter that is intended to facilitate a false killer whale to bend it if it gets hooked (http://www.nmfs.noaa.gov/pr/interactions/trt/falsekillerwhale.htm)
Large cetaceans - odontocetes	Active attraction	Longline	Camouflage	Moreno et al. 2008	Sperm whale (*Physeter macrocephalus*)	Patagonian toothfish (*Dissostichus eleginoides*)	N	N	
Large and medium cetaceans - odontocetes	Active attraction	Longline	Catch protecting gear, chilean net sleeves or *cachaloteras*	Moreno et al. 2008	Sperm whale (*Physeter macrocephalus*); South American sea lion (*Otaria bryonia*)	Patagonian toothfish (*Dissostichus eleginoides*)	?	Y	Reduced depredation rate calculated using a baseline interaction rate from a seperate study
Large cetaceans - odontocetes	Active attraction	Longline	Catch protecting gear - 'umbrella and stones' net sleeves	Goetz et al. 2011	Sperm whale (*Physeter macrocephalus*)	Patagonian toothfish (*Dissostichus eleginoides*)	?	Y	Findings were not statistically significant due to low interaction rates and small sample sizes
Large, medium, and small cetaceans - odontocetes	Active attraction	Longline	Catch protecting gear - 'chain' and 'cage' devices	Hamer et al. 2015	Multiple species	Tuna, wahoo, and mahi-mahi - higher catch rates in modified terminal ends of longlines	?	Y	Reduction in target catch depredation was not always statistically significant; shark depredation also occurred and some devices failed to function properly. Higher catch rates of target species may be due either to reduced depredation or the units attracting more fish to the baited hooks

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Medium cetaceans - odontocetes	Active attraction	Longline	Catch protecting gear - 'spiders' and 'socks'	Rabearisoa et al. 2012	False killer whale (*Pseudorca crassidens*); Short-finned pilot whale (*Globicephala macrorhynchus*)	Swordfish and tuna	?	Y	Sample sizes were not large enough to determine if the devices reduced depredation rate when compared with control hooks, and there were some device failures
Small cetaceans - odontocetes	Active attraction	Longline	Catch protecting gear - DEPRED device	Rabearisoa et al. 2015	Bottlenose (*Tursiops aduncus*) and spinner (*Stenella longirostris*) dolphins	Bait fish	?	Y	Some reduction in depredation damage by each species in a few, but not all, trials carried out off Réunion
Large cetaceans - odontocetes	Active attraction	Longline	Increase hauling speed	Tixier et al. 2015	Killer whale (*Orcinus orca*)	Patagonian toothfish (*Dissostichus eleginoides*)	N	N	Some reduction when killer whales already depredating, however depredation still occurs and there is an increased chance of fish loss from drag, together with safety concerns with fishermen safety and increased labor time
Large, medium and small cetaceans - odontocetes	Active attraction	Longline	Reduce rope or net length	Garrison 2007; Tixier et al. 2010	Pilot whales (*Globicephala* spp.); Risso's dolphin (*Grampus griseus*); Killer whale (*Orcinus orca*)	Patagonian toothfish (*Dissostichus eleginoides*); tuna and swordfish	Y	Y	Depredation is not eliminated but may be reduced perhaps from shortened hauling time; not statistically significant for Risso's dolphin
Large, medium, and small cetaceans - odontocetes	Active attraction	Longline	Predictive forecasting	Passadore et al. 2012, 2015a, b; Peterson and Carothers 2013	Sperm whale (*Physeter microcephalus*); South American sea lion (*Otaria byronia*); Subantarctic fur seal (*Arctocephalus tropicalis*); Killer whale (*Orcinus orca*); False killer whale (*Pseudorca crassidens*); Common dolphin (*Delphinus delphis*)	Sablefish (*Anoplopoma fimbria*) and Pacific halibut (*Hippoglossus stenolepis*); tuna, swordfish, and pelagic sharks	N	Y	The identification of conflict-prone regions through habitat modelling involves a high level of analytic effort with little demonstrable gains to date (e.g. Hawaii's False Killer Whale Take Reduction Plan). This could be a relatively low-cost mitigation measure but long-term data series are needed to produce more reliable forecasts, and areas that are productive for fishermen tend to be the same ones preferred by marine mammals.
Cetaceans: Large, medium, and small odontocetes	Active attraction	Longline	Decoys (acoustic)	Thode et al. 2012, 2015	Sperm whale (*Physeter macrocephalus*)	Sablefish (*Anoplopoma fimbria*)	?	Y	Studies highlight individual sperm whales that lingered in the vicinity of playbacks of longline haul recordings until recordings stopped; the longline probably would need to be set far from sperm whales to be an effective deterrent

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Cetaceans: Large, medium, and small odontocetes	Active attraction	Longline and other gear types	Move-On Rule	Auster et al. 2011; Dunn et al. 2014	Multiple species	Multiple species	?	Y	Depending on the distance from the animals to which a vessel needs to adjust, moving may not always be practical, which would need to relocate to where target catch is available. Difficult to enforce and requires compliance by all vessels.
Cetaceans - small odontocetes	Active attraction	Troll	Catch protecting gear	Zollett and Read 2006	Bottlenose dolphin (*Tursiops aduncus*)	Florida king mackerel (*Scomberomorus cavalla*) - no catch difference	Y	Y	An attached outrigger clip deterred interactions
Small cetaceans	Purposely targeted	Purse seine	Backdown procedure	NRC 1992; Bratten and Hall 1996	Multipe species	Multiple species	Y	N	The use is recommended for the Eastern Tropical Pacific where seine netters intentionally set on dolphins to catch tuna. The backdown procedure must operate in tandem with a Medina Panel and should involve swimmers to assist dolphin over the corkline.
Small cetaceans	Purposely targeted	Purse seine	"Dolphin gate" and cork-line weights	Hamer et al. 2008, Ward et al. 2015	Common dolphin (*Delphinus delphis*)	South Australian sardine (*Sardinops sagax*)	N	N	A weighted line and "gate" were inserted into one end of a purse seine to facilitate the escape of encircled dolphins. Use of these are no longer recognized as part of the CoP owing to difficulty in using them and evidence suggesting they do not work consistently in this fishery
Pinnipeds	Active attraction	Trawl	Net binding	Australian Fisheries Management Authority; Hamiltin and Baker, *in review*	Australian fur seal (*Arctocephalus pusillus*); Long-nosed fur seal (*A. forsteri*)	Hoki/blue grenadier (*Macruronus novaezelandiae*)	?	Y	Net binding is thought to have reduced fur seal bycatch in Australian fishery (Australian Fisheries Management Authority), and was proposed to reduce fur seal bycatch risk in pair trawlers used in Australia's Small Pelagic Fishery. Any apparent bycatch reduction has not been quantified.

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Pinnipeds and small cetaceans - odontocetes	Active attraction	Trawl	Multiple measures under a Code of Conduct	Deepwater Group 2017; Tilzey et al. 2006; South East Trawl Fishing Industry Assoc. (SETFIA) 2007	Australian sea lion (*Neophoca cinerea*); New Zealand sea lion (*Phocarctos hookeri*); Australian fur seal (*Arctocephalus pusillus*); Long-nosed fur seal (*A. forsteri*); Short-beaked common dolphin (*Delphinus delphis*)		?	Y	The benefits of implementing a code of conduct are unknown. The amount of bycatch reduction has never been quantified. The Code includes rapid hauling and deployment of gear, delaying deployment if seals are sighted, release of animals that are caught, closure of net during recovery and not dumping offal.
Pinnipeds	Active attraction	Trawl	Exclusion device - hard grid angled to top-opening escape	CCAMLR 2017; Childerhouse et al. 2017; Hamer and Goldsworthy 2006; Hamilton and Baker 2015a, 2015b; Hamilton & Baker, *in review*; Tilzey et al. 2006; Robertson 2015	*Arctocephalus* spp.; New Zealand sea lion (*Phocarctos hookeri*)	Hoki/Blue grenadier (*Macruronus novaezelandiae*); Antarctic krill (*Euphausia superba*); Arrow squid (*Nototodarus sloanii*)	Y	Y	Different results for forward-facing and backward-facing devices (Hamilton and Baker, *in review*). Exclusion devices have reduced New Zealand sea lion bycatch (Hamilton and Baker 2015a) and pup productivity has stabilised (Childerhouse et al. 2017). Concerns raised about levels of cryptic mortality are not supported by empirical data, although, at present, a level of uncertainty has been incorporated into NZ trawl fishery management measures.
Small cetaceans	Active attraction	Trawl	Exclusion device - hard and semi-rigid grid angled to top-opening escape	Northridge et al. 2005; van Marlen 2007; Wakefield et al. 2014; Wakefield et al. 2017	Common dolphin (*Delphinus delphis*); Bottlenose dolphin (*Tursiops* spp.)	Sea bass (*Dicentrarchus labrax*);Demersal scalefish (e.g. Lutjanidae, Lethrinidae and Epinephelidae)	?	Y	Exclusion grid may reduce dolphin mortality although may act as barrier rather than an escape route (Northridge et al. 2005).
Pinnipeds	Active attraction	Trawl	Exclusion device - soft/semi-flexible grid angled to top-opening escape	Lyle et al. 2016	Australian fur seal (*Arctocephalus pusillus*); Long-nosed fur seal (*A. forsteri*)	Small pelagic fish	N	Y	A vertical, soft rope mesh grid with top-opening escape hole initially trialed in this fishery was ineffective as mesh deformed under seal's weight causing increased entanglement risk, there was loss of of target catch with this device, and the vertical grid provided no passive assistance in directing seals to an escape hole.

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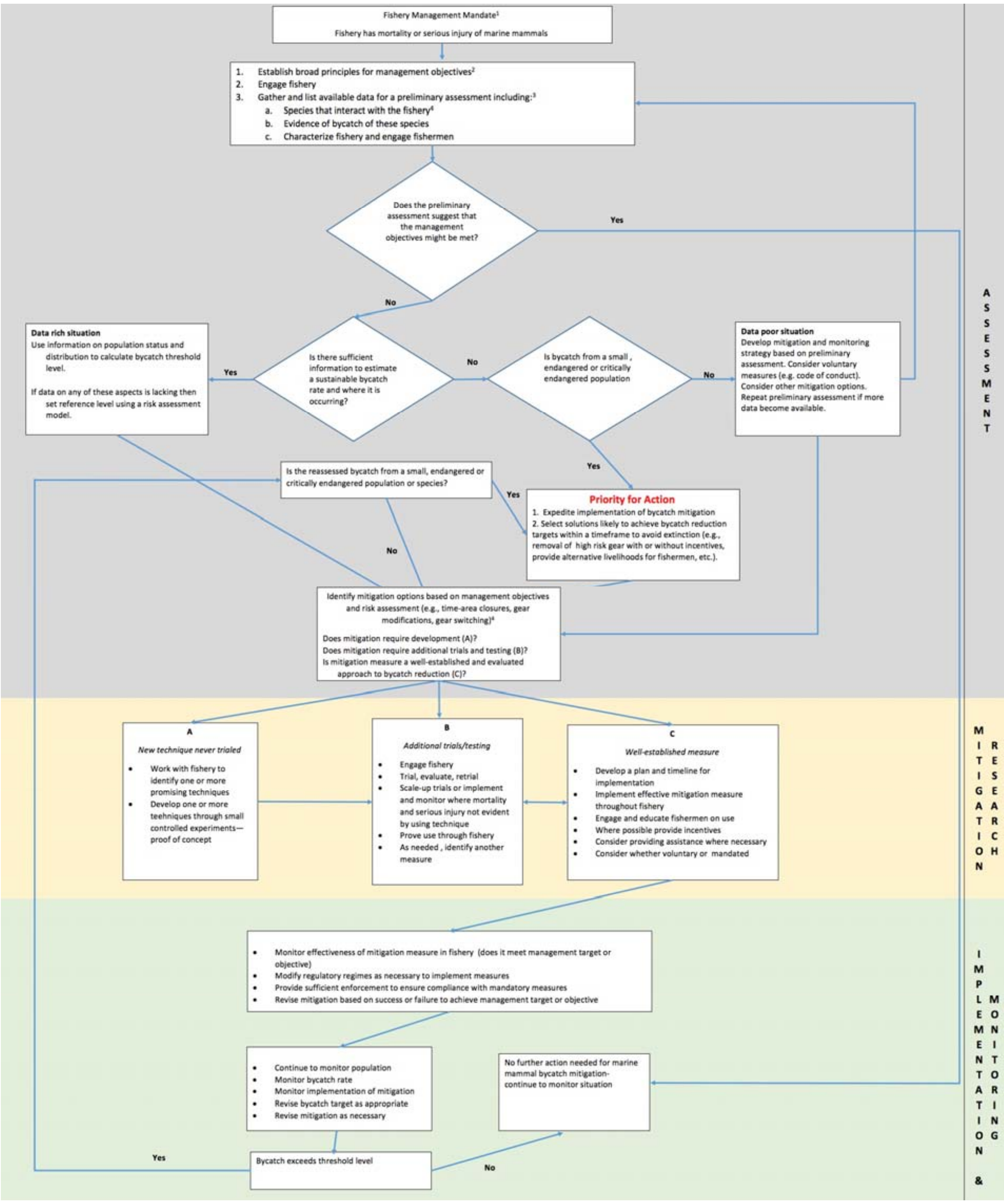
Pinnipeds	Active attraction	Trawl	Exclusion device - hard grid angled to bottom-opening escape	Lyle et al. 2016	Australian fur seal, long-nosed fur seal	Small pelagic fish	Y	Y	Bottom-opening SED with large escape hole (190 cm wide) reduced seal mortality rates in Australia's Small Pelagic Fishery. However, some dead seals dropped out of bottom-opening hole and so would not have been recorded as bycatch.
Small cetaceans - odontocetes	Active attraction	Trawl	Exclusion device - soft/semi-flexible grid angled to bottom-opening escape	Allen et al. 2014; Jaiteh et al. 2014; de Haan 2014; Stephenson and Wells 2006; Sala et al. 2017; Zeeberg et al. 2006	Common dolphin (*Delphinus delphis*); Bottlenose dolphin (*Tursiops* spp.); White-sided dolphins (*Lagenorhynchus acutus*)	Demersal scalefish (e.g. Lutjanidae, Lethrinidae and Epinephelidae); Small pelagic fish - e.g. sardinella (*Sardinella aurita*, *S. maderensis*), Horse mackerel (*Trachurus trachurus*), Anchovies (*Engraulis encrasicolus*), and Sardine (*Sardina pilchardus*)	N	Y	Recent increase in dolphin bycatch and target catch species loss using this device
Small cetaceans - odontocetes	Active attraction	Trawl	Rope or mesh barriers near net entrance	Bord Iascaigh Mhara and University of St Andrews, 2010; Northridge et al., 2005; van Marlen 2007	Common dolphin (*Delphinus delphis*)	Sea bass (*Dicentrarchus labrax*); Horse mackerel *(Trachurus trachurus*) - reduced using device	Y	Y	Video evidence of dolphins escaping net mesh barrier with top-opening escape holes covered with parallel 'bungee cords' but more design refinement and testing required
Small cetaceans - odontocetes	Active attraction	Trawl	Acoustic Deterrent Devices	Allen et al. 2014; ; De Carlo et al. 2012; Morizur et al. 2007; Morizur et al. 2008; Northridge et al. 2011; van Marlen 2007	Common dolphin (*Delphinus delphis*); Bottlenose dolphin (*Tursiops* spp.)	Sea bass, anchovies, sardine - no effect?	Y	Y	For common dolphin, some bycatch reduction from different trials, although results varied and sample sizes not always large enough. No deterrent effect observed with bottlenose dolphins.

SPECIES GROUP	BEHAVIOUR	GEAR	TECHNIQUE	REF.	BYCATCH SPECIES	TARGET CATCH	EVIDENCE TO SUPPORT (Y) OR REFUTE (N) EFFICACY?	ADDITIONAL TRIALS RECOMMENDED?	NOTES
Small cetaceans - odontocetes	Active attraction	Trawl	Auto-trawl systems	Hamilton and Baker, in review; Wakefield et al. 2014; Wakefield et al. 2017	Bottlenose dolphin (*Tursiops* spp.)	Demersal scalefish (e.g. Lutjanidae, Lethrinidae and Epinephelidae)	Y	Y	Otter-board acoustic sensors (automated system) and eliminating sharp turns and net collapse during trawling appear to have reduced bottlenose dolphin mortalities (Wakefield et al. 2014, 2017), although yet to be considered or tested as a mitigation measure (Hamilton and Baker, *in review*). It is unclear whether the acoustic sensors or change in practices reduce bycatch.

APPENDIX 5

Decision tree

This decision tree was developed during the workshop, and provides an example of the type of steps and decision points a fisheries manager might consider in developing a strategy for addressing marine mammal bycatch. Workshop participants found the exercise in producing this tree useful, and concluded that this draft should be developed further into a more useful tool. Particular polygons could be subdivided further into even more specific decision points, and provide guidance for choosing among different bycatch mitigation measures. These measures would draw from the information contained in the summary table and report.



Fishery Management Mandate[1]
Fishery has mortality or serious injury of marine mammals
1. Establish broad principles for management objectives[2]
2. Engage fishery
3. Gather and list available data for a preliminary assessment including:[3]
a. Species that interact with the fishery[4]
b. Evidence of bycatch of these species
c. Characterize fishery and engage fishermen
Does the preliminary assessment suggest that the management objectives might be met?
Yes
No
Data rich situation
Use information on population status and distribution to calculate bycatch threshold level.
If data on any of these aspects is lacking then set reference level using a risk assessment model.
Yes
Is there sufficient information to estimate a sustainable bycatch rate and where it is occurring?
No
Is bycatch from a small , endangered or critically endangered population
No
Data poor situation
Develop mitigation and monitoring strategy based on preliminary assessment. Consider voluntary measures (e.g. code of conduct). Consider other mitigation options. Repeat preliminary assessment if more data become available.
Yes
Is the reassessed bycatch from a small, endangered or critically endangered population or species?
Yes
No
Priority for Action
1. Expedite implementation of bycatch mitigation
2. Select solutions likely to achieve bycatch reduction targets within a timeframe to avoid extinction (e.g., removal of high risk gear with or without incentives, provide alternative livelihoods for fishermen, etc.).
Identify mitigation options based on management objectives and risk assessment (e.g., time-area closures, gear modifications, gear switching)[4]
Does mitigation require development (A)?
Does mitigation require additional trials and testing (B)?
Is mitigation measure a well-established and evaluated approach to bycatch reduction (C)?
A
New technique never trialed
Work with fishery to identify one or more promising techniques
Develop one or more teehniques through small controlled experiments—proof of concept
B
Additional trials/testing
Engage fishery
Trial, evaluate, retrial
Scale-up trials or implement and monitor where mortality and serious injury not evident by using technique
Prove use through fishery
As needed , identify another measure
C
Well-established measure
Develop a plan and timeline for implementation
Implement effective mitigation measure throughout fishery
Engage and educate fishermen on use
Where possible provide incentives
Consider providing assistance where necessary
Consider whether voluntary or mandated
Monitor effectiveness of mitigation measure in fishery (does it meet management target or objective)
Modify regulatory regimes as necessary to implement measures
Provide sufficient enforcement to ensure compliance with mandatory measures
Revise mitigation based on success or failure to achieve management target or objective
Continue to monitor population
Monitor bycatch rate
Monitor implementation of mitigation
Revise bycatch target as appropriate
Revise mitigation as necessary
No further action needed for marine mammal bycatch mitigation- continue to monitor situation
Yes
Bycatch exceeds threshold level
No
ASSESSMENT
MITIGATION
RESEARCH
IMPLEMENTATION &
MONITORING

Notes to Decision tree:

[1] *States and users of aquatic ecosystems should minimize waste, catch of non-target species, both fish and non-fish species, and impacts on associated or dependent species*. (FAO Code of Conduct for Responsible Fisheries 6.6) *States should take appropriate measures to minimize waste, discards, catch by lost or abandoned gear, catch of non-target species, both fish and non-fish species, and negative impacts on associated or dependent species, in particular endangered species. Where appropriate, such measures may include technical measures related to fish size, mesh size or gear, discards, closed seasons and areas and zones reserved for selected fisheries, particularly artisanal fisheries. Such measures should be applied, where appropriate, to protect juveniles and spawners. States and subregional or regional fisheries management organizations and arrangements should promote, to the extent practicable, the development and use of selective, environmentally safe and cost effective gear and techniques.* (Code of Conduct 7.6.9)

[2] These can be qualitative objectives such as 'reduce' or 'mimimise' bycatch in line with Code of Conduct for Responsible Fisheries, avoid depletion of marine mammal populations, achieve favourable conservation status, maintain marine mammal population at % of K, or achieve compliance with import regulations. *States should assess the impacts of environmental factors on target stocks and species belonging to the same ecosystem or associated with or dependent upon the target stocks, and assess the relationship among the populations in the ecosystem.* (Code of Conduct 7.2.3)

[3] This could involve running through a simple checklist of data on the fishery and marine mammal population, engaging with relevant experts on what might be needed.

[4] Mitigation techniques are described throughout Appendix 3, and can include voluntary measures, codes of conduct, gear switching, spatial and temporal closures, acoustic deterrents, and gear modifications.

[5] *…catch of non-target species, both fish and non- fish species, and impacts on associated or dependent species are minimized, through measures including, to the extent practicable, the development and use of selective, environmentally safe and cost-effective fishing gear and techniques.* (Code of Conduct 7.2.2g) *States should require that fishing gear, methods and practices, to the extent practicable, are sufficiently selective so as to minimize waste, discards, catch of non-target species, both fish and non-fish species, and impacts on associated or dependent species and that the intent of related regulations is not circumvented by technical devices. In this regard, fishers should cooperate in the development of selective fishing gear and methods. States should ensure that information on new developments and requirements is made available to all fishers* (Code of Conduct 8.5.1). *In order to improve selectivity, States should, when drawing up their laws and regulations, take into account the range of selective fishing gear, methods and strategies available to the industry.* (Code of Conduct 8.5.2).

This document contains the report of the Expert Workshop on Means and Methods for Reducing Marine Mammal Mortality in Fishing and Aquaculture Operations held in Rome, Italy, from 20 to 23 March 2018. The workshop reviewed the current state of knowledge on the issue of marine mammal bycatch, and evaluated the efficacy of different strategies and measures for mitigating bycatch and their implementation. The workshop produced some key technical outputs, including an extensive review of techniques across different gear types and species, together with a summary table and a draft decision tree which could be used to support management decision-making processes. The workshop recommended that FAO develop Technical Guidelines on means and methods for prevention and reduction of marine mammal bycatch and mortality in fishing and aquaculture operations.

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