Global Assessment of Large Whale Entanglement and Bycatch Reduction in Fixed Fishing Gear

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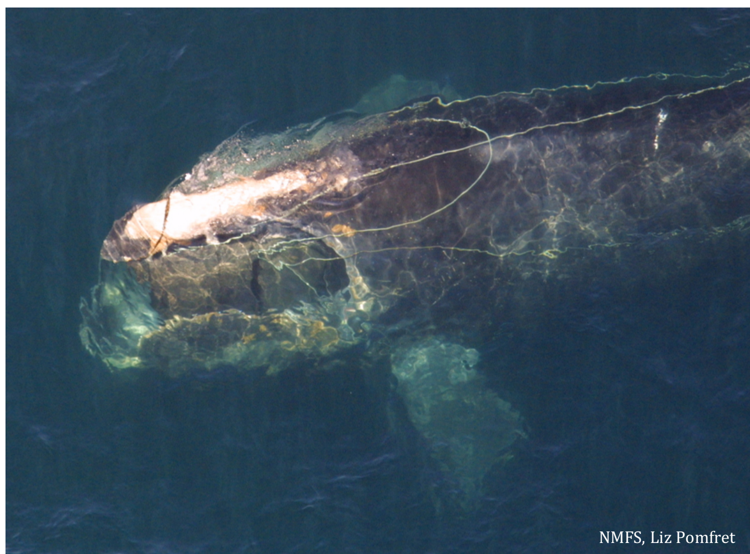
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Project Overview

The objective of this project was to peer review current research and practices worldwide for preventing the incidence and severity of large whale entanglements in primarily fixed fishing gear. A primary motivation for undertaking this review was acknowledgment that entanglement in fishing gear is among the most immediate threats to several species and populations of large whales. The goal was to identify the most promising options from a scientific perspective, and collectively highlight those that should be research priorities.

Methods

This study involved four components: (1) A preliminary global assessment of whale entanglement records in all types of fishing gear; (2) A review of entanglement prevention measures as part of an expert workshop; and (3) Development of a computer model to provide a platform for testing the relative entanglement probability of existing and modified fishing ropes.

During the course of the project, we became aware that the International Whaling Commission (IWC) was interested in holding a similar workshop, and eventually decided to include them as a co-sponsor. The Commission's objectives for the workshop largely coincided with those of the Bycatch Consortium's workshop, except for a few topics such as disentanglement that were the focus of a final "IWC Day" (*see* Appendix 1, Workshop Agenda).

<u>Global Assessment of Whale Entanglements</u>

We reviewed entanglement records for all baleen and Sperm whales, the so-called "great whales," which comprise 15 species (*Table 1*) ranging across coastal and pelagic seas, from the deep sea to shallower waters and across all latitudes. Entanglement records were compiled from published and grey literature sources, identified first through an on-line search using combinations of the following search terms: "bycatch"; fishery type (e.g. longline, trawl); "entanglement"; and species names (common and scientific). The two main sources of information were International Whaling Commission reports (1990-2013) and US Marine Mammal Stock Assessments (1995-2015). 1990 was used as the earliest date for records, mainly marking the first availability of IWC reports that have the most comprehensive global assessment available. The references for these records are provided at the end of this report as Appendix 1.

Table 1. The Great Whales.

Mysticete (baleen) whales (14 species)			
SCIENTIFIC NAME	**COMMON NAME**	**IUCN STATUS (Species)**	**IUCN STATUS (Subpopulations/subspecies)**
Balaena mysticetus	Bowhead whale	Least concern	*Bering-Chukchi-Beaufort Sea subpopulation* - Low risk/conservation dependent *Okhotsk Sea subpopulation* - Endangered *Svalbard-Barents Sea (Spitsbergen) subpopulation* – Critically Endangered
Eubalaena glacialis	North Atlantic right whale	Endangered	
Eubalaena japonica	North Pacific right whale	Endangered	*Northeast Pacific subpopulation* – Critically Endangered
Eubalaena australis	Southern right whale	Least concern	*Chile-Peru subpopulation* - Critically Endangered
Caperea marginata	Pygmy right whale	Data deficient	
Eschrichtius robustus	Gray whale	Least concern	*Western subpopulation* – Critically Endangered
Balaenoptera acutorostrata	Common minke whale	Least concern	
Balaenoptera bonaerensis	Antarctic minke whale	Data deficient	
Balaenoptera borealis	Sei whale	Endangered	
Balaenoptera edeni	Byrde's whale	Data deficient	
Balaenoptera musculus	Blue whale	Endangered	*Balaenoptera musculus* ssp. *brevicauda* – Data Deficient *Balaenoptera musculus* ssp. *intermedia* – Critically Endangered
Balaenoptera omurai	Omura's whale	Data deficient	
Balaenoptera physalus	Fin whale	Endangered	*Mediterranean subpopulation* – Vulnerable
Megaptera novaeangliae	Humpback whale	Least Concern	*Arabian sea subpopulation* - Endangered *Oceania subpopulation* - Endangered
Odontocete (toothed) whales (1 species)			
Physeter microcephalus	Sperm whale	Vulnerable	*Mediterranean subpopulation* – Endangered

The results were compiled for all broad categories of fishing gear types using FAO (2005) classifications, but also included were finfish and shellfish aquaculture facilities, and shark (beach control) nets. Excluded were anecdotal reports of entanglement in fishing aggregation devices (FADs). For each reference, whenever possible the entanglement was recorded by species, region, year, target species, type of gear involved, reporting method (*i.e.,* logbooks, onboard observers, strandings, injured or floating carcass), and outcome (dead, severely injured, released, hooked, or entangled). With respect to outcome, what constitutes serious injury is precisely defined in the case of US Stock Assessments but more variable when reported elsewhere.

Review of Entanglement Prevention Techniques

A list of existing large whale entanglement prevention and mitigation techniques was generated using various information sources compiled by the Consortium for Wildlife Bycatch Reduction, all of which are available on its website (*www.bycatch.org*). The emphasis was on techniques that might be incorporated into fishing gear or operations to prevent entanglement in the first place, or facilitate self-release of whales should they become entangled. Time-area closures, reduced fishing quotas, and other management measures intended to restrict fishing effort were not considered. The emphasis instead was on modifying gear or operational practices. Disentanglement programs, in which teams of rescuers attempt to remove fishing gear from entangled whales, are not considered in this report, except in reference to what the gear retrieved from entangled whales informs us about potential bycatch mitigation strategies.

In May of 2016, a four-day workshop was organized to review these techniques. The agenda for this workshop is provided in Appendix 2, and the participants listed in Table 2. The format involved presentations on different whale entanglement prevention techniques, followed by discussions within break-out groups. Three separate groups were organized, one to review acoustic deterrent techniques, one visual, and one to encompass all other methods. The outputs from each group were presented during a plenary session, and the discussion points made during these sessions were used to revise the final reports. Subsequent revisions to separate reports were made after the workshop. Also during the plenary, participants produced a list of recommendations, largely responding to the needs--and following the format--of IWC reporting procedures.

Each group was given some flexibility in preparing its report, but received the following instructions:

BREAK-OUT GROUPS ASSIGNMENT

Select a Facilitator and Rapporteur

General Group Objectives:

1) Summarize current understanding of the efficacy of this/these technique/s for preventing entanglement of mysticete and sperm whales
2) Suggest and describe as much as possible new techniques or ones adapted from earlier ideas for preventing whale entanglements
3) List at least three key recommendations based on group discussions that can be communicated to the IWC Scientific Committee and other major policy audiences (e.g., FAO, RFMOs)
4) Produce a written document that captures the above and addresses the information described below in the Outline.

Outline for Group Reports:

I. Summarize the technique(s) and characterize its/their variability. (For example, what different types of acoustic deterrents have been tested?)

II. What general observations seem to be consistent across the experimental evaluations of this technique?

III. Is there sufficient evidence to indicate this technique is or may be effective in preventing or significantly reducing entanglement of whales in fishing gear and other analogous structures deployed in the ocean? If not, what new information indicates whether or not this technique might have a higher probability of being effective? (For example, might acoustic deterrents be more effective if they operated at a higher sound output?)

IV. Under what circumstances, if any, has this technique been shown to be effective in reducing large whale entanglements—e.g., species, regions, habitats, fisheries, commercial or artisanal fisheries? (For example, what might explain a more ready appeal of rope-less fishing in NSW Australia lobster trap fishery vs in the near shore Gulf of Maine?) Please focus mainly on the technical rather than political, socio-economic, or cultural circumstances, although brief mention of these factors is fine.

V. Is there any basis for continuing to advocate implementation of this technique or to carry out further investigation of it?

VI. Is this technique more effective with particular species or taxa? Which ones? Is there an apparently taxon-associated characteristic (e.g., pelagic, echolocating, foraging behavior) that makes this technique more or less appropriate?

VII. Where scientific evaluations have been carried out, under what circumstances does the technique seem most appropriate—artisanal fishing, commercial fishing, target species, bycatch species, gear density, etc.)?

VIII. Please identify locations, species, or circumstances where experimental work could be easily done on the relevant topic (e.g. shark nets as a location to test color or pingers).

IX. What are the actual or potential downsides of this technique for other non-target species bycatch or the environment in general? For example, might it lead to higher bycatch in sea turtles or might it contribute more marine debris?

X. What are the most critical research priorities for advancing understanding of this technique as a potential application?

XI. Identify critical research gaps.

XII. Generally, what entanglement reduction techniques or methods considered by this group should receive research attention and seem the most promising?

Note: Please include reference to specific published studies to support observations and conclusions. Draw from the citations distributed in advance of the workshop and please add important ones not provided.

Table 2. Large whale entanglement prevention workshop participants.

NAME	AFFILIATION	COUNTRY
Tim Werner, M.S	Bycatch Consortium/New England Aquarium (NEAq)	US
Amy Knowlton, M.S	NEAq	US
Moira Brown, Ph.D.	NEAq/Canadian Whale Institute	Canada
Brian Kot, Ph.D.	Antioch College	US
Scott Kraus, Ph.D.	NEAq	US
Jeffry Fasick, Ph.D.	University of Tampa	US
Ken Baldwin, Ph.D.	University of New Hampshire	US
John Haviland	South Shore Lobster Fishermen's Association (SSLFA)	US
Mike Lane	Massachusetts Lobstermen's Association	US
Rob Martin	SSLFA	US
Patrice McCarron	Maine Lobstermen's Association; Maine Lobstermen's Community Alliance	US
Kristan Porter	Maine Lobstermen's Association	US
Geoff Liggins, Ph.D.	New South Wales Department of Primary Industry, (NSW-DPI)	Australia
Scott Westley	NSW lobster fisherman	Australia
Jason How, Ph.D.	Western Australian Fisheries and Marine Research Laboratories	Australia
Rob Harcourt, Ph.D.	Macquarie University, Australia	Australia
Hawsun Sohn	Cetacean Research Institute	S. Korea
Ed Lyman, M.S.	NOAA	US
Dan Lawson, Ph.D.	NOAA	US
Sheila Garber	Englund Marine	US
Nina Young, M.S.	NOAA	US
Jim Partan, Ph.D.	Woods Hole Oceanographic Institution	US
Dave Mattila	International Whaling Commission (IWC)	US
Mike Anderson-Reade	KwaZulu-Natal Sharks Board	S. Africa
Greg Donovan, Ph.D.	IWC	UK
Cathy Merriman, M.S.	Fisheries and Oceans Canada	Canada
Sean Brillant, Ph.D.	Canadian Wildlife Federation	Canada
Rich Langan, Ph.D.	University of New Hampshire	US
Milton Marcondes, DVM	Instituto Baleia Jubarte	Brazil
Peter Tyack, Ph.D.	University of St. Andrews	UK
Nette Leverman	Ministry of Fisheries, Hunting & Agriculture	Greenland (Denmark)
Russell Leaper, M.S.	IWC	UK
Lorenzo Rojas-Bracho, Ph.D.	Instituto Nacional de Ecología y Cambio Climático	Mexico
Marco Flagg	Desert Star Systems	US
Erin Summers, M.S.	Maine Department of Marine Resources	US
David Morin	NOAA	US
Tonya Wimmer, M.S.	Marine mammal biologist	Canada
Kate McLellan-Press, M.S.	UMASS-Amherst	US

Results

<u>Global Assessment of Whale Entanglements</u>

Pots and gillnets are the two types of gear most commonly involved in baleen whale entanglements, at least where most monitoring of entanglements occurs (Johnson et al., 2005; Groom and Coughran, 2012). Nevertheless, there are many reports of entanglement occuring in most other types of fishing gear, including longlines, trawls, seine nets, stow nets, and weirs, and shark or beach protection nets. Records of entanglements in marine aquaculture fish cages and shellfish "longlines" are not well documented but have been reported from different parts of the world. At least one record exists of aquaculture gear off the North American East Coast causing an entanglement of a NARW (*Eubalaena glacialis*) (Johnson et al. 2005). Reports from other parts of the world include two Bryde's whales (*Balaenoptera edeni*) entangled in mussel spat lines off New Zealand (Lloyd 2003), a North Pacific right whale (*E. japonica*) in mussel farm gear off N. Korea (Young 2015), and, in 2016, a humpback whale (*Megaptera novaeangliae*) in British Columbia.

Table 3 shows that whale entanglements involve all large whales and all types of fishing gear. Nevertheless, using this information to draw conclusions about entanglements is highly limited and potentially misleading, such as using them to characterize the extent of entanglements, as well as the degree to which they affect particular species and gear types. This has to do with several reasons, which include the following:

(1) Reports of entanglements involve a high variability in the ability of individuals reporting them on how to distinguish gear and species;
(2) The degree of monitoring of entanglements depends on the extent of observer (formal and informal) presence that varies between areas and over time;
(3) Most whale entanglements go undetected, not only because of sporadic monitoring but also because whales can pick up gear, and shed it or die as a consequence without ever being observed entangled, and often leaving no trace;
(4) As shown in Table 2, many entangle events did not identify the gear or species involved; and
(5) As shown by high scarring rates, such as those of North Atlantic right whales (83% of all individuals in 2009 bore scars from ropes (Knowlton et al, 2012]), entanglement records do not include those in which the whale shed the gear without previously recorded as being entangled; and
(6) The rates of entanglements probably are influenced by the size of the populations and the extent to which different gears are used or deployed within whale habitat.

Even in the eastern US that arguably carries out the largest and most active monitoring of whale entanglements, fewer than 10% of entanglements are observed (S. Landry, pers. comm.).

Table 3. Numbers of entangled whales reported from various sourced for the period 1990-2015, attributed to different fishing gear types, where indicated (*see text*).

	Gillnet	**Driftnet**	**Shark Control**	**Other net**	**Pot/Trap**	**Longline**	**Seine**	**Trawl**	**Pound net/Trap net**	**Weir**	**Other**	**Aqua-culture**	***Unknown gear***
Bowhead Whale				1	2								1
North Atlantic Right Whale	3				17		2					1	36
North Pacific Right Whale													1
Southern Right Whale			18	4	1	1							8
Fin Whale		7			2			1					26
Sei Whale							1						7
Bryde's Whale	2	1				1							4
Omura's Whale		1					1						
Blue Whale		1			1								2
Common Minke Whale	481	44		415	470	2	4	27	1563		3	3	1875
Antarctic Minke Whale				?		1							
Humpback Whale	87	4	28	8	106	10	2	9	16	1	1		183
Gray Whale	10	7		2	11		1	2	4				39
Pygmy Right Whale	1								21			1	8
Sperm Whale	6	21			1	7							8
Unknown Balaenopterid	7	16	1	1	3	28	6						42

Figure 2. A Korean “set net” (weir) visible by satellite.

Review of Techniques

The techniques reviewed below focus on modifying the gear so that there is a reduced probabilty of either encountering it or becoming entangled in it, or, if contact occurs, facilitating passive disentanglement. When considering bycatch mitigation measures, workshop participants recommended that, where possible, the ‘ideal’ hierarchy for action in descending order should be to: 1) avoid encounters with fishing gear, 2) reduce entanglements in such gear where encounters cannot be avoided, and 3) minimize mortality associated with entanglement when entanglement occurs. This does not imply that actions of all three kinds cannot proceed in parallel, and promising (e.g. simple, effective, and cost effective) actions that enjoy support among fishermen should be encouraged. Within this framework, assessments of the overall cost-benefits of different options (including consideration of user and conservation goals) can help identify priority techniques for testing and implementation.

In general, the modifications to fishing gear and practices conceived of to date were intended to be used in pot, and, to a lesser extent, gillnet gear.

Whale entanglements are a global phenomenon yet all the techniques referred to here originated or were initially evaluated in the eastern US (except the initial test of an acoustic deterrent and humpback whales which was carried out in Canada), largely as outputs from the Atlantic Large Whale Take Reduction Team (ALWTRT). The ALWTRT consists of fishers, government researchers and administrators, marine scientists, and non-governmental organization representatives, and was established by law under the US Marine Mammal Protection Act to work collaboratively to reduce the bycatch of large whales off the eastern US to near zero. Although some of the modifications reviewed have been implemented in pot and gillnet fisheries in this region, for the most part their implementation remain unsupported by rigorous scientific studies showing that they reduce entanglements.

Table 4 lists the techniques reviewed, and organized under three categories: reducing probability of *encounter*, reducing probability of *entanglement*, and mitigating entanglement if it occurs.

Table 4. *Modifications to pot and gillnet gear or practices reviewed for preventing or mitigating large whale entanglements.*

Reduce Probability of Encounter	Reduce Probability of Entanglement	Post-entanglement mitigation of injury/entanglement severity or mortality
Minimize ratio of vertical lines to units of gear deployed	Materially stiffening rope	Post-entanglement release mechanisms
Sinking or neutrally buoyant groundline	High tension rope	
Submerged endlines or rope-less fishing	Reducing the use of knots in ropes	
Reducing rope or net length	Whale free buoy	
Grappling	Slippery rope	
Visual enhancements	Decreasing gillnet mesh size	
Sound-emitting devices		

“Gear tending” was initially considered but later removed. The group concluded that if whales approached or interacted with tended gear, the response by fishermen would involve a technique covered in Table 4, such as the use of net stiffening, or employ acoustic or physical harassments which are covered by the other sectional reports. Although the third column in Table 1 involves techniques designed to facilitate whales becoming free from gear once entangled, the focus is on passive release that does not require human intervention by disentanglement teams.

TECHNIQUE: Minimize ratio of vertical lines to units of gear deployed

What is it? Reducing the overall number of vertical lines used in a pot or gillnet gear fishery without reducing bottom gear. This includes ”trawling up”, a term used by the US National Marine Fisheries Service (NMFS) in the northeastern US to describe a pot fisher who uses fewer buoy lines per number of total pots, by attaching more pots/trawl (pot string) in a single deployment (NOAA 2015). It can also involve using fewer buoy lines/gillnet string, as described in a study carried out in Mexico to reduce sea turtle bycatch (eg Peckham et al, 2016). A lower number and density of vertical lines is presumed to reduce overall entanglement risk by reducing the probability that whales will encounter ropes.

General observations. Although mathematically entanglement risk reduction should result by applying this method, how closely the theoretical corresponds to actual reductions in entanglement risk is unknown. Increasing the number of traps/trawl to $\geq$5 would have no net reduction in vertical lines in the Gulf of Maine lobster pot fishery because “trawls” with 5 or more traps require the addition of a second endline (Tetreault and McClellan, 2015). Deploying more traps per buoy line might result in pot fishers increasing the diameter of these ropes to handle the additional bottom weight of the gear, and heavier ropes are considered more of an entanglement risk to large whales (Knowlton et al 2016). Heavier gear might also lead to an increase in rope parting and consequently the possibility of more derelict gear. In a pot fishery that has strings of pots connected with groundlines, the entanglement risk from vertical lines might be offset by an increase in the length of groundlines, although if these are negatively buoyant and rest on the seafloor as most are in the eastern US by law, entanglement risk in the water column should be minimal. Both vertical lines and groundlines entangle whales (Johnson et al 2005), and the impact of US government regulations requiring the use of sinking groundlines in pot fisheries off has yet to be determined (Pace et al 2014).

Evidence? Intuitively, this technique should reduce entanglement risk if vertical lines are mostly involved in entangling whales relative to horizontal lines (such as groundlines and longlines) or gill net panels. Nevertheless, rarely do we know which component of the entire gear set caused the initial entanglement.

Any examples that have shown it to work as a deterrent? We know of no examples that have shown conclusively that this technique leads to reduced entanglement risk. Reducing the number of buoy lines in a Mexican gillnet showed significant reductions in sea turtle entanglements (while recording similar target catch per unit effort although with reduced catch value) (Peckham et al 2016), however apart from involving a different group of animals, the component of the gear would almost certainly have involved the net panels and not the ropes.

Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? It has already been implemented in the northeastern US. There is intuitive support for reducing the number of endlines/unit of gear, so especially where the threat is high and entanglements in vertical lines are known to occur, it is worth investigating further.

Species/taxa specificity. This technique would apply to any species in which entanglements are known to occur in vertical lines.

Under what circumstances would it be most effective? Circumstances in which it might be feasible are those in which the fishery can incorporate more gear per vertical line. In some part of Maine (USA), more complex and rocky sea floor topographies challenge the ability of fishers to deploy multiple traps that may not come to rest in the correct orientation or result in lines getting hung up on rocks. There may be limitations on the use of this technique for smaller vessels, which are less well equipped for hauling and handling heavier bottom gear that would result from increasing the number of traps/trawl.
Where could an experiment be done? A fishery that optimally meets the following criteria: (1) there are high entanglement rates in vertical lines; (2) it is possible to distinguish between the components of gear involved in the initial entanglement (vertical vs other ropes or nets) using gear marking; and (3) there is sufficient observation of entangled whales to record the gear involved. Possible areas worth considering are the eastern US and the California Dungeness crab fishery, although long-term monitoring is a more likely approach.

Actual or potential downsides. As indicated above, fishers cannot precisely target fishing sites if traps are now part of a longer trawl than previously used, there is the potential for more severe entanglements resulting from fishing with heavier bottom gear that might involve a change to larger diameter ropes, more ghost gear could result if multi-trap trawls use only one vertical line as opposed to one on each end where the second line is used as a back-up haul line if the first becomes unavailable, and greater physical disturbance to benthic habitats might eventuate by using more groundlines that rest on the sea floor while the gear is set and hauled.

Research gaps/priorities. Validation that the concept shows actual reduction in entanglement risk would be useful. In different fisheries, it is important to understand the relative risk of vertical lines to other gear components, as well as if lowering the risk from vertical lines might be offset by other fishing changes made in response. Specifically, along the US east coast to what extent does "trawling up" lead to adopting ropes of larger diameter that might increase entanglement incidence or severity? It would be useful to record changes in scarring rates through monitoring the impact of this measure, while controlling for other variables, as well as gear marking schemes that distinguish between vertical and horizontal ropes. Results from the northeastern US should be monitored to inform other areas in which it potentially might be used.

TECHNIQUE: Sinking/neutrally buoyant groundline
What is it? Having the line that connects traps to one another be negatively or neutrally buoyant so that it lays on or near the seafloor versus up in the water

column (NOAA 2007). *Variability.* The performance of these ropes depends on the configuration of gear, how it is deployed, and oceanographic conditions such as seafloor substrate, tides, and currents. When ropes are taut in between traps they may not rest on the bottom. Chains are used in Canada between traps, although it has nothing to do with preventing whale entanglements. A fisher will sometimes use sinking ropes or chains as a preferred fishing method, such as in Alaska demersal longlines and gillnet leadlines.

General observations. Fishers have communicated a number of concerns regarding the use of sinking groundlines. Among these are poor handling on deck; tension during hauling due to the rope becoming lodged under rocks; limited "play" in ropes under tension leading to snapped lines and dangerous handling conditions; loud noise when run through the hauler; weakened sections of line resulting from chafing on the seafloor; and a higher difficulty in predicting when the rope is nearing the end of its operational life (Ludwig et al 2015). Probably the most significant consequences involve a higher risk of personal injury when hauling these ropes and the increased expense of needing to replace these ropes more often than float ropes. Neutrally buoyant lines were eventually removed from consideration by the ALWTRT in favor of sinking groundlines because the former were shown to still frequently occur high enough in the water column such that entanglement risk would not necessarily be reduced.

Evidence? Groundlines used in the northeastern US lobster pot fishery are known to entangle whales (Johnson et al 2005)--although in what proportion to buoy lines remains undetermined--and the assumption is that the encounter risk is reduced by keeping them at the seafloor. Nevertheless, some whales do feed at or near the seafloor so it cannot be assumed that the risk is entirely eliminated. No experimental or monitoring data has shown that this technique prevents entanglement in groundlines, although the ALWTRT generally assumed it would be beneficial. Since the regulatory requirement went into place in the northeastern US (NOAA 2007) no monitoring data shown the efficacy of the measure.

Any examples that have shown it to work as a deterrent? No.
Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? Intuitively it should reduce entanglement risk but to what extent remains unknown. Monitoring its use in the northeastern US and further investigation is warranted.

Species/taxa specificity. We assume all great whales occur at the sea floor frequently enough to suggest that this should apply across all species of great whales.

Under what circumstances would it be most effective? The technique would be more appropriately used in areas with light currents and tides where positively buoyant groundlines (specific gravity <1) are more likely to rise into the water column. Sea floors that have rugged or rocky bottom types make their use less practical.

Where could experiment be done? [See this section under "Minimize ratio of vertical lines to units of gear deployed."]

Actual or potential downsides? When grappling is required, which occurs when buoy lines are lost, it is made more difficult because the rope sits on the bottom rather than forming a loop above it. This can potentially result in more lost gear. Ropes degrade more quickly from siltation and abrasion, particularly under the crushing force of the hauler, requiring more frequent replacement (Allen et al 2008). It is also conceivable that ropes would be less visible to whales that could become entangled in them while feeding at the sea floor. (See additional fishing concerns, above.)

Research gaps/priorities. A useful gear-marking scheme is needed that can identify the rate of groundline entanglements.

TECHNIQUE: Sub-Surface Vertical Lines or rope-less fishing

What is it? The retention of buoy lines at or near gear on the sea-floor except during setting and hauling. *Variability*. 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 acoustic command given by a fishing vessel that activates a mechanical release.

General observations. 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) 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)

Generally, two challenges largely explain why the use of submerged vertical lines is 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, such as when draggers inadvertently pass over fixed gear on the sea floor. In heavily utilized fishing grounds, fishers would have a higher likelihood of setting gear on top of one another. Second, acoustic releases, which give fishers 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 lines and buoys for each gear set, as well as deck-based acoustic signal transmitters. Third, depending on how the rope is placed into its container as well as how it is released from it, there may be a higher incidence of rope becoming tangled or snared at the instance of retrieval. When compared with galvanic and timed releases, acoustic releases provide the most flexibility in terms of when a fisher chooses to retrieve bottom gear. Galvanic timed releases (GTRs) are the least reliable in activating at the exactly desired release time, and a fisher 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 at least avoid entanglement risk during that period. Of all the techniques, the at-call acoustic release system is the one that removes nearly 100% of the risk of whale encounter with the buoy line except: (i) with any length of rope that may be used between the trap/gear and the bag/container of submerged buoy line; (ii) during hauling of the gear post-release; or (iii) in the event of system failure (e.g. buoy line tangling post-release before buoys reach the surface or incorrect deployment by the fisherman).

Evidence that reduces entanglement. An at-call acoustic release system has been in use by two lobster fishers in New South Wales, Australia for the last three years. The majority of the other lobster fishers trapping in mid- and outer-continental shelf depths in this fishery use GTRs to submerge their buoy lines and have used this system for over a decade. Prevention of whale entanglements was not the primary motivation for using these releases; it was instead an interest in hiding the presence of gear from potential thieves and also avoiding ropes being caught up in the propellers of passing boats. During the last two decades, the period in which the majority of fishers working traps on the mid- and outer-continental shelf have used these submerged endlines, there have been no reported whale entanglements attributable to the deep-water lobster fishery (G. Liggins, pers. comm.). Thus, while there is no conclusive experimental evidence regarding the relative performance of these gear modifications with respect to whale entanglements, it is the most compelling technique in terms of minimizing the risk of encounter and entanglement.

Any examples that have shown it to work as a deterrent? No.
Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? Yes. The focus of investigation is more related to the practicality for the fishery than in evaluating the bycatch reduction benefit for large whales, given that removing lines from the water seems of unquestionable benefit to whales. Further investigations should include cost-effectiveness and practicality of implementing this approach in different fisheries, such as through small-scale pilot demonstrations. The objectives of these pilot projects would be to introduce fishers to the technology, investigate fishery-specific modifications to release gears, and to stimulate ideas for refinement of the technique by fishers.

Species/taxa specificity. Should apply equally across all species, but this technique would likely be the most critical to consider where fishing with buoy lines overlaps with the most endangered whales.

Under what circumstances would it be most effective? In the case of southeastern Australia, the incentives for fishers to use this technique did not include prevention of whale entanglements, which just happened to provide an additional benefit. If there are areas where fishers have incentives to use subsurface buoy lines, this may stimulate industry innovation in the development of practical systems. Among the most challenging locations would be small-scale non-industrial fisheries with limited capital for using such systems, and in areas with very high gear density prone to frequent gear conflicts. Use of submerged vertical lines might be an option for providing future access to areas closed to fishing due to entanglement, and an incentive to fishermen to develop innovative and practical techniques.

Where could experiment be easily done? Seeing as this technique is considered the most advisable for preventing whale encounters with vertical lines, we suggest it be tested in multiple fisheries where entanglements in these lines is an issue.

Actual or potential downsides. It is difficult to foresee any downsides for whales, even by using acoustic signals that would be triggered so infrequently. Conceivably, gear might be lost due to malfunctioning releases, however having a system for communicating with gear using acoustics increases the likelihood of identifying the location of gear for retrieval by grappling. Including vertical lines on the opposing end of a gear set also submerged and secured with releases, or the use of a weaker line at this terminal end of the set can also serve as back-up retrieval systems in the event that the primary hauling line fails or is lost.

Research priorities. There may be several fisheries already using GTRs, such as in the New South Wales lobster fishery, and it would be useful to learn from their experience. As mentioned above, this technique should be tested and evaluated in different fisheries to determine how well it might be developed and used practically. If some rope is to extend above the bottom trap or net to which the main haul line and flotation is secured, the length should be sufficiently of short length so as not to pose an entanglement risk, and some determination could be made to keep it at a length that is not long enough to enwrap a body part. A critical priority is to identify measures that can increase the visibility of the full extent of this gear underwater in the absence of buoy markers, or to identify other approaches for avoiding these conflicts.

TECHNIQUE: Reducing rope or net length

What is it? Using the minimal length of rope or gillnets so as to reduce the overall amount of gear in the water column for reducing the probability of entanglements. *Variability*. This measure applies to a wide range of gear components, such as vertical lines, the groundlines separating pot strings, surface lines between buoys, gangions, gillnet panels and conceivably longlines. Under this technique we include avoiding wet storage of gear, because it also reduces the exposure of gear to whales (NMFS, 1997). In the southeastern US calving grounds of the North Atlantic right whale, NMFS limits the number of gillnet panels and vertical length of gillnets (to 25 meshes deep) (NMFS 2006).

General observations. Fishers in general should favorably receive ideas that minimize the extent of gear used while maximizing catch-per-unit-effort, especially seeing as it can lower gear expenses and potentially lead to reducing entanglement probability. Whales entangled in less rope can reduce injury severity by minimizing the drag of gear being pulled by a whale entangled in it (Van der Hoop et al 2014). Also, it is possible that it would also reduce the complexity of the entanglement (eg, extensive wrapping) by reducing the chance of trailing gear snagging additional gear from other sets.

Evidence of entanglement reduction. In general, entanglement risk should be reduced however there have been no specific studies, and it is unclear how much gear reduction might be required to show significant reductions in entanglement probability.

Any examples that have shown it to work as a deterrent? No.
Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? Yes, especially since many fishers seem willing to adopt it as part of generally advisable practices (eg, McCarron et al 2015).

Species/taxa specificity. No.

Under what circumstances would it be most effective? Wet storage seems the most obvious idea to implement wherever feasible because it entirely removes gear from the water. It can also be readily considered by fishers that seasonally relocate gear from shallower to deeper water fishing grounds and might otherwise use excessive lengths of rope for shallower depths in anticipating the move to deeper water sites.

Where could experiment be easily done? Our group did not come up with any ideas or rationale for a specific experiment.

Actual or potential downsides. Reducing the length of individual gear components as part of single sets should not lead to an increase in overall gear length from multiple sets/deployments. In addition, if reducing vertical line length results in higher vertical line tension, one study suggested that entanglements involving these ropes could be more severe because taut lines can produce more severe lacerations (Baldwin et al, 2012). Also, lines under higher tension might lead to a higher incidence of ropes parting, that could result in more gear losses. However, lower line scope at the surface could reduce the incidence of conflicts with other vessels at the ocean surface, and shorter lengths of gear at depth might produce fewer overhangs with another fisher's gear. All these considerations need to be evaluated on a case-by-case basis.

Research gaps/priorities. (1) Model potential entanglement reduction risk under different rope/net length scenarios as part of a cost-benefit analysis; (2) Study the impacts of using reduced rope length on the characteristics of fishing gear (line tension, gear loss, etc.); and (3) Promote workshops among fishers in particular fisheries to come up with proposals for minimizing the use of gear while maintaining adequate catch levels.

TECHNIQUE: Grappling

What is it? For strings of two or more fishing pots connected to one another by groundline, the use of grappling instead of vertical lines for retrieving gear to the surface.

General observations. Lobster pot fishers operating off the eastern US sometimes grapple for gear when they lose hauling lines. The concept here involves consideration of whether this method might become standard practice in order to eliminate entanglement risk of vertical lines altogether. With the mandated use of sinking groundlines in much of this fishery, fishers report lower success in recovering bottom traps using this method (Ludwig et al, 2015).

Evidence that reduced entanglement. [See this section under, above]
Any examples that have shown it to work as a deterrent? [See this section under "Sub-surface vertical lines", above]

Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? In cases where fishers are willing to use this technique, its evaluation should be encouraged, assuming that it includes a method for identifying the presence of gear to other fishers for avoiding gear conflicts. It does come at a potential risk of producing more lost gear. An evaluation by fishermen in Maine of grappling for lobster trap trawls (two or more pots connected by groundline) reported a huge 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 a huge difficulty of using the technique under high winds, currents, and wave heights (Pemaquid Fishermen's Co-Op 2012).

Species/taxa specificity. None.

Under what circumstances would it be most effective? In areas where multiple strings of pots are used, where sea bottom topography is relatively flat, and where high gear densities are avoidable.

Where could experiment be easily done? In areas where sinking groundlines are not used, where for other reasons there is a high probability that grappling would be successful in retrieving gear, and where the increase in hauling time can be minimized or not seriously compromise a fishers operational constraints owing to increased haul time.

Actual or potential downsides. Unless the presence of the gear can be identified to all fishers operating within the same area, it will be difficult to avoid gear being set on top of other sets, and gear that is inadvertently dragged to a different location will be difficult to locate and retrieve. [See too this section under "Sub-surface vertical lines", above]

Research gaps/priorities. (1) Promote the evaluation of this method in areas where fishers have an interest in testing it; and (2) Examine methods for identifying the presence of subsurface gear to all fishers so as to avoid gear conflicts.

TECHNIQUE: <u>Sound-emitting devices</u>
What is it? Devices that have been used to generate a behavioral avoidance response in cetaceans.

General observations. Pingers have been shown to work to reduce bycatch in certain small cetacean species but not for reducing entanglement of large whales, apart from reported by Lien et al. (1992) off Newfoundland. That study occurred in an area of low visibility, high turbidity water where a more profound effect of acoustics might be expected. No specific large-scale experiments similar to those conducted for small cetaceans have been conducted to evaluate the efficacy of acoustic devices for preventing entanglement of large whales but the experiments that have been conducted do not show any avoidance response.

If a device could be designed to cause an avoidance response of a few tens of meters then it could be applied to fisheries with low densities of gear. In areas with high densities of gear an avoidance response is unlikely to be useful because deviations from one piece of gear may result in whales heading into other gear (see Figure 1). Where gear is so dense that deterrents would force animals out of an area then acoustic devices are unlikely to be an effective solution and other techniques are needed.

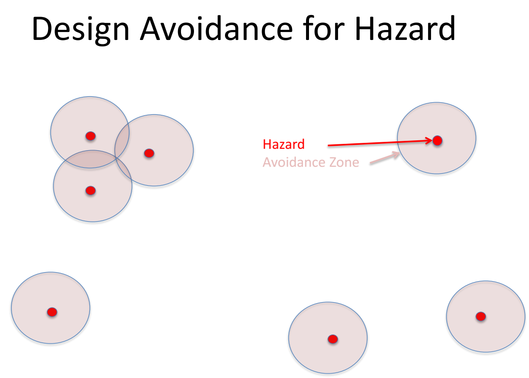

Figure 3. Examples of configuration of hazards (the three hazards in the top left) and avoidance zones where proximity of hazards can result in deterrents being ineffective.

Cumulative responses may also have negative impacts which need to be evaluated through approaches such as Population Consequences of Disturbance, PCoD (New et al., 2015). For example, a large number of small responses can have a substantial total impact. Moving whales to the outer edge of a migratory pathway is likely to have less impact than moving whales out of feeding or breeding areas.

Animals may view fishing gear as an opportunity for depredation rather than a hazard. Therefore, in any potential application of acoustic devices there is a need to be aware of the potential for acoustic devices to attract animals of the target species or others towards gear.

One area where pingers have been used for large whales has been in South Africa off the coast of Kwa-Zulu Natal. Pingers were moved off the nets to rope moorings around 50-100m away (on the side of approaching whales during migration Figure 2), because there were concerns that holes in the nets presumed to have been created by whales correlated with the location of the pingers. This could have been due to animals investigating the pingers. There are 37 beaches protected by 22km of netting and 107 drum lines. Drum lines with baited hooks were introduced to reduce bycatch of non-target species. This has reduced bycatch by 47.5% in the last 8 years (M. Dicken, unpublished). Some nets have had pingers and some not. The pingers were moved between beaches of higher incidences over the years. If a beach had high incidence in one year then pingers would be deployed there the following season. The apparent increase in humpback whale entanglements has closely followed the estimated 11% increase in the population.

Figure 4. Example deployment of nets (between red marks) and pingers (yellow circles) off Kwa-Zulu Natal, South Africa (from M. Anderson-Reade).

Evidence? The great majority of use of acoustic devices to reduce bycatch has been the development of 'pingers' for small cetaceans (Dawson et al. 2013). Responses to acoustic signals are reviewed in (Southall et al. 2007) including responses of large whales to sound sources. Many of these responses demonstrate some form of avoidance (Nowacek et al. 2007; Southall et al. 2007). For example sonar has been used in commercial whaling to cause whales to flee at the surface (Brownell et al. 2008). Nowacek et al. (2004) tested a device (173dB source level, 0.5-2kHz) for alerting right whales to approaching ships. Received levels of 133 to 148dB provoked a response in which whales tended to come to the surface. Humpback whales have shown a strong avoidance response to killer whale playbacks (Curé et al. 2015). Sperm whales have shown avoidance responses to navy sonar at received levels between 120 and 160dB (Miller et al., 2012). Baleen whales have shown responses at received levels of 120dB for continuous sounds (Richardson et al. 1995). The response of all individuals will be context dependent. There are considerable differences in responses of different species to sound stimuli (Ellison et al., 2011). Banging on boats and creating noise have also been used to try and encourage some species out of an area in a similar to drive fisheries for small cetaceans. Banging is also routinely used to attract whales to vessels (Lewis, 1990). For example, there were large difference in responses to sonar type playbacks depending on taxa e.g. pilot whales stand their ground (Curé et al. 2012) whereas beaked whales and minke whales show strong avoidance (Sivle et al., 2015).

The goals of acoustic devices for reducing entanglements in fisheries activities can be divided into categories, defined here as deterrent, alarm or alert. However, there is basically a continuum between devices with intended responses ranging from just alerting an animal to provoking an avoidance or a flight response. Deterrents aim to provoke an avoidance response to keep animals out of an area. Alarms intend to make an animal aware of a hazard sufficient to keep it away from the hazard. Alerts are just intended to make an animal aware of the hazard.

There have been limited experiments with acoustic devices aimed at large whales in a fisheries context. Lien et al. (1992) reported that acoustic devices reduced collision and entanglement rates of humpback whales in cod traps off Newfoundland. Peak frequency of these devices was around 4kHz with source levels around 145dB, received levels were unknown. More recently most experiments have involved the Future Oceans (Fumunda) F3 and Fishtek Banana pingers which were both designed to alert baleen whales. These have a peak frequency around 3kHz and the F3 has a rated source level output of 135dB. However, tests in Australia have measured actual source levels of 98 - 118 dB (Erbe et al., 2011) and 108 -147 dB (How, J. pers. comm.). Fishtek Banana pingers have also been used (measured source level of 134dB (Crosby et al., 2013) or 135dB (How, J. unpublished)). The large variation in the output levels for the same model of commercially available devices have complicated evaluations.

Studies of F3 have not shown any measurable avoidance response in humpback whales (Harcourt et al., 2014; How et al., 2015). Additional studies using an amplified signal from a F3 and a 2-2.1 kHz upswept tone of 1.5 ms duration repeated every 8 seconds (Dunlop et al. 2013) did not find any measureable response (Pirotta et al., 2016). Given what is known of responses of humpback whales to other sound sources (e.g. Frankel and Clark, 2000) it is not surprising that these devices would not generate received levels high enough to provoke an avoidance response.

An alternate approach initiated by fishers in Alaska was to field test the F3s in several fisheries. Unfortunately, these studies have not been able to provide adequate data to evaluate whether they are effective. None of the devices used in fisheries to date match the acoustic characteristics of sounds that have been shown to evoke an avoidance response in baleen whales (Richardson et al. 1995; Goldbogen et al., 2013).

Any examples that have shown it to work as a deterrent? With fisheries, only in Newfoundland with humpback whales in the Lien et al (1992) study.

Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? Yes.

Species/taxa specificity. Cetaceans respond very differently to acoustic signals by species.

Under what circumstances would it be most effective?

Characteristics of fishery interactions where there might be most benefit from development of acoustic devices
Practical use of acoustic devices is most likely to be successful for fisheries with the following characteristics:

- Gear which has a high threat level (including time and area by presence of species of most concern)
- Low density of gear
- Displacing whales a relatively short distance on migration may be more appropriate than displacement from feeding or breeding areas
- If depredation is occurring then critical that devices do not attract animals to gear
- Testing efficacy during development phase requires large numbers of animals and potential interactions
- Cost of devices relative to units of fishing gear and catch value
- Situations where there are less likely to be alternative ways for whales to detect gear (e.g. high turbidity where visual cues are ineffective)
- Needs to be practicable and safe to deploy

Acoustic devices are unlikely to be successful if:

- Gear is set at a high density
- Fishing occurs in critical whale habitats
- If deployed as the only measure where management is attempting to achieve a true zero take (e.g. critically endangered species).
- Pinger failure rates are high
- Cost is too great
- Safety concerns with deployment or recovery
- Background noise levels are too high
- If social or safety issues (general public) are not acceptable

Recommendations for experimental work
There have not been any comprehensive experiments of efficacy of acoustic devices for reducing large whale entanglement. The elements needed to design such experiments would include;

(a) Specify an acceptable response for the type of fishing gear that is of concern and then design an experimental protocol to evaluate if this response is being achieved. In most situations an avoidance response is desirable, not panic flight. If habituation is a concern a startle response (see Appendix I) may be required. The received signal and repetition rate need to be such that the animal detects the signal in time to avoid the obstruction. An alert (e.g. lure) that attracts animals is also undesirable.

(b) It may be possible to test stimuli on other populations, as proxies, than the one for which there is most concern (e.g. there are some abundant populations of southern right whale but the ones of most concern such as in SE Australia are very small).
(c) On a species/context specific basis, repeat similar experiments to Harcourt et al. (2014) but have at least two source levels plus a control, higher source levels might attract a stronger response than desired and one which is hoped to provide the desired response. The design needs to be able to detect when undesirable flight responses may occur as well as appropriate avoidance to avoid gear. Measurements need to be made of source levels, received levels and transmission loss covering the range of environmental conditions experienced during the experiments.
(d) Experiments to test efficacy at reducing whale entanglement need to assess other impacts (e.g. those listed in section IX) as well.

Where could an experiment be done? [See below]

Actual or potential downsides.

- Acoustic deterrents may affect fish catches.
- Introduction of noise into the environment can affect all species including stress in the species the devices are targeting.
- If pingers are not functioning properly then there is a risk of actually increasing entanglement risk as has been shown for harbour porpoise (Palka et al. 2008; Dawson et al. 2013).
- Any reduction in habitat availability needs to be taken into account.
- For some species (e.g. right whales and gray whales), forcing animals further offshore may increase predation risk or make animals less available for human use such as subsistence hunting or whale watching.
- Shipping density also need to be taken into account to ensure that ship strike risk is not increased.
- Impact on humans including noise levels for divers, swimmers and surfers which may affect hearing

Research gaps/priorities.

1. Data already gathered from Kwa-Zulu Natal, South Africa, using Future Oceans F3 pingers on shark nets should be analysed before expanded use of these devices in other areas, to see if any effect (e.g. a difference in entanglement rate between nets with and without devices) can be detected.

2. If any initiatives are taken to use pingers within any fishery then these need to be associated with an appropriate ongoing fisheries monitoring programme. Such monitoring needs to include fishing effort, catch rates of the target species, evaluation of the functioning of the pingers, and power to detect either positive or negative effects on whale entanglement rates (including proximity to the pinger). Reporting and monitoring systems which put a burden on fishers need to demonstrate potential benefits to the fishers involved. Electronic reporting can reduce the monitoring burden.
3. Develop and test acoustic devices using sound characteristics that have been shown to produce avoidance responses in large whales. Devices aimed to produce a startle response could be developed and tested particularly in situations where cumulative sound exposure and habituation are a concern. Experiments should be conducted to determine the minimum required source level for a given species and situation.
4. If a device can be found that shows clear evidence of an avoidance response then there will be a need to design adequate long-term experiments that evaluate the efficacy at reducing entanglement in specific gear types and in actual fisheries. Such experiments also need to consider long term impacts (e.g. potential habituation), practicalities of use, and potential impact on catch rates of target species.

In addition to the research priorities already outlined there is currently limited understanding of large whale hearing capabilities. Anatomical studies provide insight into the range over which they can hear but not the sensitivity thresholds. Obtaining permits to conduct relevant experiments will remain an issue in many countries.

Glossary

Pinger – an acoustic device designed to emit sounds audible to cetaceans

Drumline – an unmanned aquatic trap used to lure and capture large sharks using baited hooks, typically deployed near popular swimming beaches with the intention of reducing the number of sharks in the vicinity and therefore the probability of shark attack, but with minimal bycatch.

Depredation – the removal (stealing) of bait or catch from active fishing gear, or the raiding and removal of penned fish by marine predators

decibel: The decibel (dB) is a logarithmic scale for measuring a quantity with respect to an arbitrary reference level, which is 1 microPascal for underwater sound.

Sound Pressure Level (SPL): for a sound pressure p, the sound pressure level is defined as 20 $\log_{10}$ (p/1 microPascal). Where values are given in the report these are not fully specified as to whether they refer to root mean square (rms) or peak-to-peak values. In addition the frequency band needs to be specified. For accurate comparison of values it is essential to check the specification within the original reference.

Source Level (SL): the sound pressure level of a sound source recorded at 1 m distance from the source.
Received Level (RL): the sound pressure level of a sound source recorded at 1 the receiver.
Transmission Loss (TL): The decrease in sound level in dB as it propagates from 1 m to where it is measured.

TECHNIQUE: Visual enhancements

What is it? Altering the color, luminosity, or shapes of fishing gear to make them more detectable to large whales.

General observations. The baleen whales are all rod monochromats (Meredith et al. 2013), i.e., they essentially see in black and white, probably have lower resolving power than terrestrial mammals, and probably have good vision in low-light conditions. Given this, it is not intuitive to think of color as a valuable option for alerting large whales to the presence of fishing gear. However, in baleen whales, color sensitivity is centered in the blue-green section of the color spectrum (478-493nm), and they have no visual sensitivity above 650nm (red). Hence the ocean background light will appear bright, or white, to these whales, and red objects in the foreground are likely to appear black as the whales are insensitive to long wavelength light. In addition, the use of black rope is inadvisable because it is difficult to visualize in a dis-entanglement situation on black whale skin. Therefore, the use of rope color in preventing entanglements includes: 1) defining the spectral sensitivity of the whale eye; 2) defining the spectral quality of the underwater background light; and 3) defining the spectral reflectance of the colored rope in different illuminating conditions during the day and night.

The spectral sensitivity of the baleen whales has been well described (Bischoff et al. 2012, Meredith et al. 2013) with the rod base retinae absorbing maximally between 484-493 nm. The spectral quality of the underwater background light is highly variable depending on the time of year, distance from shore and other variables. The spectral reflectance of the colored rope is defined by the pigments used to paint/synthesize the rope or by inclusion of bioluminescent pigments for detection at night, as described below.

Fluorescence is the emission of light by a substance subsequent to the absorbance of light, typically of higher energy. Fluorescence is not persistent as fluorescent materials stop glowing upon removal of the excitation source. Phosphorescence, unlike fluorescence, is persistent as phosphorescent materials continue to glow for several hours after the excitation source is removed. Forms of chemo-luminescence such as light-emitting diodes (LEDs) have been used in field studies as deterrence devices of marine vertebrates such as sea turtles (Watson et al., 2005; Southwood et al., 2008; Wang et al., 2010). However, to date there is no literature describing the use of fluorescence, nor phosphorescence, as a deterrent of marine vertebrates in bycatch reduction studies.

The actual "entanglement prevention" effectiveness of early gear detection by a whale is dependent upon the ability of that whale to respond appropriately, e.g. turning rapidly, to avoid the gear. Therefore, avoidance of gear may be a function of both how alert the whale is to its environment (the antecedent behavioral context), and its turning radius and velocity relative with regards to its distance from the gear. These factors are not well known, although information exists for right whales (Mayo and Marx, 1994) and humpback whales (Edel and Winn, 1978), and may be available from other studies (see The Center for Coastal Studies disentanglement data for details).

Even before discussing the detail of which prevention approaches (e.g. visual, acoustic) are worth investigation for particular species, fishery types and areas, it must be remembered that the ability of a whale to respond in time to avoid entanglement is a key factor. If an animal is alerted to gear but at a distance too short for it to react effectively, then the alert will be of no value. In some circumstances it could conceivably make the entanglement more complex (e.g. if the whale turns to try and avoid the gear this may actually result in gear being caught in more places on the body). At a minimum it would be valuable to examine the 'turning radius' of an animal, which needs to be related to a number of factors that might influence its response time after detection occurs i.e. how alert is it to its environment (this will include behavior at the time and swim speed). In simple terms, if the turning radius of an animal is 'x' metres but the (although improved) detection by the new visual or other alert is less than that, the method will not be effective in prevention. It is important that efforts are made to examine this issue either through existing data or as a component of new studies.

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 being not significant. In another experiment Kot et al. (2012) found that minke whales exhibited statistically significant behavioral responses to certain colors of rope in nearshore habitat. Although the strongest behavioral changes in this experiment were reported during trials with white and black ropes, behavioral changes occurred at distances approaching 100 m and it is not likely that this was a visual response at these distances (Kot et al., 2012). One other experiment providing information 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 (Beamish, 1978).

Altering rope color is an attractive option for 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 of gear by the fishermen. Further, 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 response from some species.

Light Emitting Diodes (LEDs) and Other Artificial Light Sources

Light emitting diodes (LEDs) and other artificial light sources such as cyalume chemlights (chemical light sticks) offer an alternative visual stimulus to alert marine mammals to the presence of gear. Technology has been rapidly advancing to offer these relatively simple and low-power demand visual aids for marine research applications. Recreational fishers and commercial fishing have used lights of various power sources on the surface and below the water to attract bait fish to lure game fish in for harvesting (Watson et al 2005).

The hypothesis is 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, there needs to be ideal environmental conditions for the animal to detect the gear in time for an avoidance response. A number of questions need to be answered first before exploring the capability of artificial light sources; what is the visual acuity and light sensitivity of large whales, is constant illumination ideal or does a strobe effect have a greater impact?

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 overall promise with a turtle bycatch reduction of 40% and having negligible impact on catch or catch value.

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 of bycaught non-targeted species of concern 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 was collected from the experiment using the LEDs (S. Kraus, unpublished data).

There are a number of concerns from the fishing industry standpoint. How would this technology stand up to the rigors of commercial fishing? Developing this equipment could quickly become cost-prohibitive and still have difficulty withstanding daily use in the fishing industry. Compared to chemical light sticks used in a number of fisheries, LEDs are ten times the cost. Also, the constant or strobe illumination should have no impact on the fisherman's targeted species and not attract any natural predators.

Geometric and Color Pattern Modifications

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 likely generates 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 (Fig. 1; Kot et al., in submission). Pilot tests with LED units and 20cm mylar streamers yielded limited avoidance response behaviors in right whales (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. However, the uniform strength and consistency of the underwater environment would need to be studied to determine if these applications are feasible. Some patterns of color are widely known to create effects of illusory motion (Zanker and Walker 2004) and "peripheral drift" in stationary objects (Kitaoka and Ashida 2003). Evidence also suggests that thick-banded patterns may be easier to detect by animals than thin-banded patterns (Stevens et al. 2008). One recommendation for future experimental trials with ropes and mysticetes should include thick-banded patterns of underwater artificial lights. The illusory effects of motion from the bands, and the artificially-enhanced thickness from the artificial light corona (Kraus, pers. comm.), could enhance the target strength of existing fishing gear ropes.

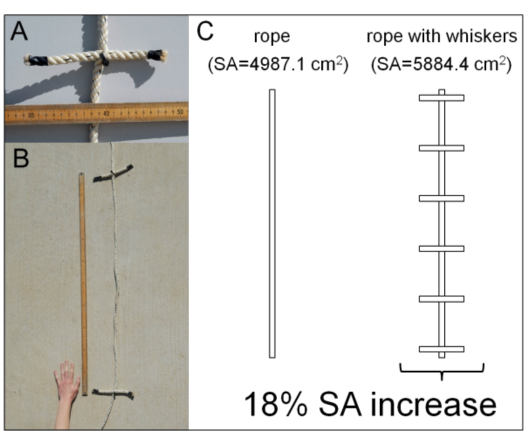

Fig. 3. Experimental rope with 20cm, "whisker" add-on devices that increase standard rope surface areas (SA) by 18% (Kot et al., in submission)

Evidence that reduces entanglement. No.

Table 5. Summary Table on Visual Deterrents

Visual Deterrents	**Evidence for whales**	**Fabrication Feasibility**	**Research Needed**	**Likelihood of Effectiveness**	**Cost**	**Application Concerns**	**Publications**
Color Rope	right, minke, fin	High	Lab, field, more species, location and context specific studies	High at surface, depth and light dependent species dependence, fishery density	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	High	Sea Turtles, targeted catch reduction	Wang et al., 2010; Watson et al, 2005; Southwood et al, 2008
Streamers, Enhancers	minke, humpback, fin	High	Field studies		Low	Entanglement risk; disentanglement hindrance	Kot et al., in submission;
Stripes/Blocks	None	Medium	Field studies		Unk.	Unknown	Stevens et al., 2008; Kitaoka an Ashida, 2003; Zanker and Walker, 2004
Fluorescence	right whale	High	Lab, engineering field	Potentially high at depth	Unk.	Sea Turtles	

Any examples that have shown it to work as a deterrent? 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 whale could see the ropes at least 4 meters away, an avoidance response by the whales can prevent collisions with ropes. Underwater visibility in temperate latitudes where whales are present is less than 20m, and frequently below 10 meters. 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 in the early morning and in the evening suggest 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 do not want to hit ropes, and will make drastic maneuvers to avoid collisions when they encounter them. Red and orange ropes are likely to improve the distance of detection to a point where whales have ample distance to execute successful avoidance behaviors. This theory 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.

Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? The studies carried out to date have encouraging results suggesting that this technique should be further evaluated.

Species/taxa specificity. So far trials have only been carried out with NARWs and minke whales, however mysticetes are all rod monochromats. 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 to be different levels of entanglement risk due to swimming depth, behavior at night, or whether an animal is alone, or in a group. 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 around the encounters. 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.

Under what circumstances would it be most effective? [*See below*]

Where could experiment be easily done? [*See below*]

The following criteria should be considered when identifying suitable sites:

- Fisheries with a known bycatch rate and relatively small group of fishermen
- Fishermen have an interest in stewardship and are willing to participate
- Ideal conditions e.g. season, climate
- Predictable occurrence and behavior of whales
- Whale populations whose survival or recovery will not be jeopardized by this work.
- Consider comparative studies in different habitat areas for the same species, e.g. feeding areas first, and if positive results are achieved, consider

conducting subsequent experiments in other habitat areas including more sensitive areas e.g. breeding grounds.

- Funding sources will need to be identified to support the research costs and to support fishermen's costs of changing their equipment and otherwise participating.

Actual or potential downsides. In addition to ones described above, visual enhancements might also cause reductions in target or increases in the bycatch of other species.

Research gaps/priorities.

Priorities

a. Behavioral response and bycatch reduction of fluorescent ropes;
b. Nighttime behavior of the animal and their ability to detect and resolve the gear at night;
c. Physics and engineering of rope—need for long-lasting pigments, fluorescence and glow-in-the-dark at low cost

Gaps

a. Turning radius of large whales (under various conditions)
b. Color Nets: reanalyze the shark net data to confirm whether there is a difference between yellow and black
c. Other Considerations: spectral changes of the rope over time; diel migration characteristics of prey;
d. Vision—retinal characteristics of other baleen whales; underwater visual processes; light sensitivity; characteristics of the tapetum lucidum; number of photoreceptors per area; ganglion cell density; rod outer segment length and width; focal length; visual acuity (field of view); pupil diameter (dilated and constricted); accommodation; pupil light response; do they possess circadian rhythm.
e. Illumination—LEDS (strobe and consistent), glow-in-the-dark rope as a bycatch reduction measure

While any geometric or color pattern modification of ropes must be tested in the field for real application in a fishery, lab and field studies must first demonstrate that the modifications do not hinder disentanglement efforts. Future research should also examine the terrestrial and human literature to identify known types of visual startle responses in different taxa. Including information from this literature, new types of rope enhancement devices should then be developed to increase the visual target strength of rope to elicit visual detectability, startle response, or avoidance behavior by mysticete whales. Any promising designs would then require testing for potential application in commercial fisheries.

Key Recommendations for Research and Application

Studies which advance our understanding large whale vision and the application of visual deterrents offer a means to modify rope or other gear components to increase detectability and allow for the potential for whales to avoid fishing gear.

I. To have a significantly robust scientifically protocol, fisheries must be identified that are isolated and have entanglements of whales that are conducive to pilot studies where visual deterrents can be tested.
II. To understand whether visual deterrents are effective, studies should be conducted for various large whale species under various locations and environmental conditions (coastal vs offshore, turbid vs clear) and behavior (migration, breeding, feeding) to determine which visual (e.g., color or geometric) modifications to gear effectively deter whales.
III. To understand the potential for use of visual deterrence under low light conditions, conduct a system evaluation of underwater spectral radiance, whale visual capabilities and behavior, and underwater visibility as it pertains to whale entanglement prevention.
IV. Based on the extremely limited empirical data available to date, the most promising visual deterrence technique that merits further attention and implementation through fishery trials: Conduct an operational experimental fishery (e.g., Brazil or Korea) to test long wavelength (orange/red) fluorescent ropes to determine the bycatch per unit effort and degradation of the rope color and fluorescence over time.

To have a significantly robust scientifically protocol, fisheries must be identified that are isolated and have entanglements of whales that are conducive to pilot studies where visual deterrents can be tested.

Evidence suggests that whales perceive certain colors more strongly than others, and controlled field experiments are the ideal way to understand how this phenomenon may be used to reduce large whale entanglement in commercial fisheries. This recommendation reflects the need to identify priority sites worldwide where such field studies could be conducted in a manner that is safe for whales and for fishermen. A review of fisheries worldwide should be conducted to identify suitable locations where studies can be undertaken to test whether using visual deterrents will reduce large whale entanglement rates. By starting with relatively simple fishery scenarios, knowledge may be gained that will support subsequent investigations in more complex fisheries and in more sensitive whale habitat areas.

The purpose of such studies is to use colored rope in existing fisheries to attempt to observe whether:

- Whales exhibit avoidance behavior
- Entanglement rate changes

To understand the potential for use of visual deterrence under low light conditions, conduct a system evaluation of underwater spectral radiance,

whale visual capabilities and behavior, and underwater visibility as it pertains to whale entanglement prevention.

Applying Vision to Bycatch Reduction
We intend to make recommendations to improve fishing gear detectability to whale species vulnerable to entanglement by studying their visual abilities and the optical properties of the gear in the surrounding light environment. Cetaceans possess the ability to evade fixed-fishing gear provide the gear is detected at distance. Like echolocation, vision allows the animal to detect objects at a distance providing time for decision making and executing maneuvers. Each species' visual abilities vary due to their evolutionary history and the complexities of the marine light environment. Unlike the terrestrial light environment, the marine light environment is highly variable in color and brightness, and is strongly affected by factors such as turbidity, viewing angle, and depth (Jerlov,1976). The following events occur for objects to be visible underwater: (1) reflected light must differ from the background in color and/or brightness (Johnsen, 2002), (2) the color of light from the background or object must be detectable by the animal's retina and (3) the size of the object must be detectable relative to the animal's visual acuity. This approach of studying vision for bycatch reduction has been successfully applied to sea turtle conservation. In a 2006 technical memorandum, NOAA compiled studies of sea turtle sensory biology from a team of experts to form a comprehensive plan for sea turtle bycatch reduction (Swimmer and Brill, 2006). The findings from this report have helped produce methods that have successfully reduced sea turtle bycatch (Wang et al., 2010, Alessandro and Antonello, 2010). A comparable study for cetaceans that would allow suggestions of fishing gear modification to reduce entanglement remains to be done.

Color Sensitivity of Whales
To better assess the visibility of fishing gear coloration to whales, genomic analyses of the wavelength sensitivity of whale retinae are needed to characterize retinal spectral sensitivity. Because light is absorbed by the visual pigment molecule (an opsin protein and a chromophore), amino acid sequences of the opsin protein can be used to estimate the wavelength sensitivity of the photoreceptors and thus determine color sensitivity of the cetacean retina (Fasick and Robinson, 2000).

Calculation of Cetacean Visual Acuity
To calculate the minimum diameter of gear detectable by cetacean visual systems, a combination of retinal histology on preserved cetacean eyes and compiling known cetacean visual acuity estimates from the literature is needed. Visual acuity, the ability to discern objects at a distance, can be estimated using retinal ganglion cell (RGC) density values and eye morphometrics. These analyses require measurements of the eye, including axial and transverse lengths and retinal arc estimations. Ganglion cell density and distribution can be measured by manual cell counts over 1-mm grids. Counts can then be converted to cells/mm2 and mapped topographically to the retinal sphere. Estimates of underwater visual acuity can be calculated from the spatial resolution of the retina at the regions of high RGC density

and the distance from this point on the retina to the lens. Visual acuity is expressed as the inter-cell angular distance (cells/deg2) as described above. Image processing algorithms can be used to model how the gear appears to a viewer with a specific visual acuity at a relevant set of distances.

Modeling of Underwater Light
To determine the most conspicuous reflectance (i.e., spectra and brightness) of fishing gear, the underwater light characteristics of waters where any visually modified gear might be tested, should be modeled using depth profiles of inherent optical properties and chlorophyll-a concentrations from the World-Wide Ocean Optics database (http://wood.jhuapl.edu/). Underwater radiance distributions can be calculated from 350 to 800 nm at 10 nm intervals and from the surface down to 500 m depth at 10 m intervals for multiple solar elevations. Underwater illumination is dependent upon the sky irradiance (Gregg and Carder, 1990; Harrison and Coombes (1988), water absorption (Pope and Fry 1997), the particle scattering function (Petzold (1977), chlorophyll fluorescence (Prieur and Sathyendranath1981) and Raman scattering by the water (Stavn and Wiedemann, 1988; Gordon, 1999). By integrating these factors, sidewelling irradiance (all light striking a vertical surface) can be estimated, and the reflectance spectrum that results in the most conspicuous presentation of fishing gear in each locale can be determined.

TECHNIQUE: Materially stiff rope
What is it? Increased bending resistance of a rope, also referred to as rope "hardness" or "firmness." *Variability*. Ropes can vary in stiffness due to the different materials used in their construction, by changing the properties of the fibers, or from different manufacturing processes (eg, tighter lay ropes, number of rope yarns/strand).

General observations. In Western Australia, lobster pot ropes that have a harder lay than those used in the eastern US and Canada still entangle southern right and humpback whales, although it is possible that they do produce fewer entanglements if softer lay ropes were used.

Evidence that reduces entanglement. No.

Any examples that have shown it to work as a deterrent? No.

Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? The fact that entanglements occur in hard lay ropes as confirmed from gear retrieved from entangled whales, suggests they have a low probability of being effective as a prevention technique, although it is possible the use of these ropes might reduce entanglements.

Species/taxa specificity. If there is any deterrent effect, it would likely be with whale species and individuals of smaller body size that would not exert as much a force that larger species could to overcome the stiffness property of a rope and become entangled.

Under what circumstances would it be most effective? Not considered.

Where could experiment be easily done? If gear could be identified from entangled whales, a comparison of entanglement rates might be possible between trap fisheries of California spot prawns in southern and northern California, where soft lay ropes are used in the south and hard lay in the north. The Virtual Whale Entanglement Simulator model developed by researchers at Duke University and the Bycatch Consortium could also be used to examine the outcomes of entanglement rates using stiffer ropes.

Actual or potential downsides. It is more difficult to splice stiffer ropes so fishers tend to knot them together instead. Knots are generally discouraged by NOAA Fisheries because they are assumed to be more likely to lead to entanglements. The increased stiffness of these ropes might also produce more severe injuries.

Research gaps/priorities. Without any indication that stiff ropes reduce entanglement risk, among the various techniques warranting further research this one does not seem to be a top priority. The assumption that stiff rope would be effective in reducing whale entanglements remains untested and a relatively inexpensive way to evaluate it further is through computer modeling.

TECHNIQUE: High Tension Rope

What is it? Increasing rope tension using the counter forces of surface flotation and bottom weight to create a taut line. The assumption is that high-tension lines make it harder for a whale to become entangled because they have less of an entangling property. The concept is therefore similar to that of rope stiffened materially. *Variability*. The degree of tension depends on the amount of weight and flotation used, as well as the rope's tensile strength, and can be influenced by tides, currents, and winds. Negatively buoyant (sinking surface) ropes to connect buoys to bottom gear are also required in pot gear along much of the eastern US because they are presumed to be more taut than float rope which is sometimes slack in the water during particular tides and current flows (NMFS 1997). A similar idea considered by the ALWTRT was a "two buoy system" that would 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 mandating 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 feeding at or near the ocean surface. An unrelated objective was to avoid conflicts with boat propellers on lines floating at the surface. Lastly, reduced scope can increase line tension which many members of the ALWTRT assume would reduce entanglement probability.

General observations. Too much weight or flotation can create impractical fishing conditions, especially seeing as load cell measurements of lobster pot gear off the northeastern US are generally low except during hauling (Salvador et al, 2002). Also, changing tides, currents, and winds can make it difficult to maintain a constant degree of tension in the line.

Evidence that reduces entanglement. High tension lines are used in easternmost Maine, employing an anchor off the terminal lobster pots of a pot string. At least one record of an entanglement from this region has been documented, off Cutler (according to a *Summary of NMFS Gear Analyses [1997-2007]* presented at the 2009 meeting of the Atlantic Large Whale Take Reduction Team). However, too few records of where a whale initially got entangled exist to conclude if this gear configuration poses more or less of a risk. Furthermore, a field study by Baldwin et al (2012) that simulated encounters between a model of a right whale flipper and ropes at different tensions determined that high-tension lines might cause more severe injuries to whales. Despite the lack of evidence, many continue to promote this approach as an obvious solution to whale entanglements (Fairbanks, 2016).

Any examples that have shown it to work as a deterrent? None.

Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? Given the generally widespread assumption that these ropes should lead to fewer entanglements, including by US stakeholders in the mussel aquaculture field (Price et al, 2016), the potential of this technique should receive further investigation. (See also this section in "Materially stiffened rope").

Species/taxa specificity. (See this section under "Materially stiffened rope").

Under what circumstances would it be most effective? Assuming taut ropes would help prevent entanglements, this technique would be most appropriate in fisheries where a wider diameter rope could be used under high tension, which should be applicable in an aquaculture facility (fish cage or mussel farm) or in structures such as fish aggregating devices (FADs). The advantage of a wider diameter rope is that if it came into contact with a whale the contact area would be spread over a wider area of tissue that might allay concerns about an increase in severe lacerations from taut lines of thinner diameters.

Where could experiment be easily done? There may be locations where tests of different rope tensions might be permitted for non-endangered whales that follow fairly predictable migratory paths (Humpbacks in NSW, Australia? Minkes in the Gulf of St. Lawrence?). Simulations could also be run using the whale entanglement computer model.

Actual or potential downsides. Entanglements that did occur in taut ropes might involve more severe injuries. Excessive flotation and weight could put undue strain on vessel haulers and create other operational hazards to fishermen.

Research gaps/priorities. Despite the widespread notion about taut lines as a technique for preventing whale entanglements, no evidence exists to indicate whether or not it would be effective. (See the above section on experiment ideas).

TECHNIQUE: Reducing the use of knots in ropes

What is it? When connecting two pieces of rope, avoiding the use of knots in favor of more uniform attachments such as splices.

General observations. The assumption is that knots increase the likelihood that a rope would get snagged on baleen or on an appendage, and upon contact with a whale would provoke a thrashing behavior that would increase probability of whale becoming entangled (NMFS, 1997). Knots do however also reduce the breaking strength of a rope at the location of the knot, so they could also serve as a type of weak link.

Evidence that reduces entanglement. None.

Any examples that have shown it to work as a deterrent? None.

Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? Rope knotting remains a widespread practice, and there is no evidence supporting assumptions about its likelihood of increasing entanglement risk. Probably best that it simply be promoted as a recommended practice.

Species/taxa specificity. Unlikely, although less relevant for sperm whales that lack baleen.

Under what circumstances would it be most effective? Not clear.

Where could experiment be easily done? We did not formulate any idea for an experiment.

Actual or potential downsides. Probably not.

Research gaps/priorities. The practice is probably worth discussing with fishers where whale entanglements are frequent enough that they hinder population recovery, and worth promoting as a "best practice." Knotted and unknotted ropes might also be run through samples of baleen plates and whale flippers to compare the degree of bodily harm and if there is a difference in how they become lodged. This should include a comparison of the degree of damage to baleen, which could affect whale feeding success.

TECHNIQUE: Whale free buoy

What is it? A buoy with a flexible, tapered stem made of urethane or some other plastic

(Goudey 2004). Conceived as an alternative to the typical bullet-shaped lobster buoy used in the northeastern US 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 after contact.

General observations. 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 or perhaps even damaging a larger area of it 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 US regulations for many east coast fisheries that use buoy lines.

Evidence that reduced entanglement. None.

Any examples that have shown it to work as a deterrent? No.

Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? 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.

Species/taxa specificity. Unlikely.

Under what circumstances would it be most effective? If entanglements were definitely known to largely occur from initial contact with the whale flipper, which probably is not the case.

Where could experiment be easily done? Not advised.

Actual or potential downsides. As above.

Research gaps/priorities. It would be instructive to know the extent to which entanglements occur during feeding, and the proportion of entanglements that occur as a result of initial contact with the head or mouth versus the flipper. Understanding this would help identify which among several bycatch mitigation techniques have better promise.

TECHNIQUE: Slippery rope

What is it? A rope developed to be more slippery of have less friction so that a whale might shed gear more easily. The concept was reported in 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).

General observations. Based on the engineering and fishing challenges associated with developing and using such a rope, no further consideration of it is provided here.

TECHNIQUE: Reducing gillnet mesh size

What is it? Decreasing the mesh size of a gillnet. In the southeastern US calving grounds of the North Atlantic right whale, the legal requirement of gillnet mesh size was reduced from 5 inches to less than 3 inches stretch mesh (NMFS, 2006).

General observations. We are unaware of any study showing that smaller meshes are less likely to entangle marine mammals. However, it seems less likely that an appendage of a large marine mammal would be entangled in smaller meshes, although the threshold size for when entanglement might be more or less likely remains unknown.

Evidence that reduced entanglement. Not to our knowledge.

Any examples that have shown it to work as a deterrent? No.

Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? Much of the focus on whale entanglement prevention has focused on the ropes used in pot and gillnet fisheries, and less so on the net panels. Ropes may pose the greatest risk of all gear components in these fisheries, but equally possible is that net panels—sometimes observed on entangled whales—may also pose significant risk. Unfortunately, with so few observations of the instant in which whales become entangled in fishing gear, the proportion of entanglements caused by net panels themselves remains undetermined for gillnet entanglements.

Species/taxa specificity. For the period 1993-2002, records of Humpback and North Atlantic right whale entanglements in which the gear was retrieved or identified by NMFS, show that in all but one case—where the species and gear could be determined—gillnet entanglements involved humpback whales (Johnson, 2005). In general, although gillnets entangle multiple baleen whale species, it is possible that humpbacks in particular might benefit from effective entanglement prevention techniques targeting gillnets. Nevertheless, if only ropes were retrieved from entanglements, then it may not always be clear if they were part of gillnet, pot, or other gear.

Under what circumstances would it be most effective? In fisheries that entangle relatively smaller whale species of calves, and in which decreased mesh size would continue to yield adequate size and composition of target fishes.

Where could experiment be easily done? It seems unlikely to identify a location where entanglement events would be frequent enough so that the relative proportion of entanglement due to netting versus ropes could be determined. **Actual or potential downsides**. Reducing mesh size might not produce optimal target catches.

Research gaps/priorities. The extent to which gillnet panels contribute to whale entanglement rates remains a major gap in our knowledge. Smaller twine sizes might facilitate whales breaking free from gillnet panels while still having fishers retain target catch. In general, physical modifications to gillnets for reducing bycatch have not received much attention (Gray, Broadhurst et al. 2005, Grati, Bolognini et al. 2015), and may yet provide some promising techniques.

TECHNIQUE: Post-entanglement release mechanisms

What is it? A variety of options are currently used or have been proposed for weakening portions of pot and gillnet gear, and also line cutting devices, to help passively free a whale after it has become entangled. *Variability*. Weak links attached just below surface buoys and within the head rope and panels of gillnets, are the most widely used technique under legal requirements for many eastern US lobster pot and gillnet fisheries (NOAA 1997a, b; 2000; 2002). In the case of bottom set gillnets, there is also a requirement to anchor them on each end, which provides a counterforce to flotation for facilitating line parting upon contact with a whale (NMFS 1997), and can also increase line and net tautness (NMFS 2006). All other devices under this category exist only as concepts or have received some testing and evaluation but have never become adopted by fishers. For example, reference has been made to a "zap link" that would be incorporated into the groundline of lobster traps, intended to release a whale if a force of 200 lbs were exerted on it (*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). Presumably this idea was abandoned from consideration by NMFS once the sinking groundline rule went into effect. Other weak link ideas include splicing in pieces of manila into the typical plastic polymer ropes used by the industry (Smolowitz and Wiley 1998), breakaway buoys (Smolowitz and Wiley 1999), and cutting buoy lines into sections with their ends re-aligned by encasing the bitter ends in a braided sheath (referred to as "South Shore rope" based on a design being advanced by lobster fishers in southern Massachusetts and the rope manufacturer Novabraid). Additional devices or techniques include the following:

Buoy line messenger system - A device that would transport 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 up to the surface when a "messenger" (such as a cleat) would be run down the tag line and attached to it.

Thwartable bottom link – 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, while the gear is deployed the device was designed to secure the rope from moving in the direction of the blade unless a force is exerted on the vertical line by an entangled whale.

Knots – Knotting reduces the breaking strength of the line at the location of the knot.

Timed whale release – A device to which a vertical line is attached 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).

Galvanic releases - Metallic links on fishing gear designed to eventually dissolve, thereby releasing any entrapped or entangled animal. 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).

Time tension line cutter - 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).

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.

Lipid soluble rope. A fishing line that would dissolve once embedded in the blubber of a large whale.

Note: Similar devices have been proposed and some of these may be found through an online search of patents.

General observations. Weak links are the only devices in this category that have so far become widely used, at least in the eastern US. The remaining ones have either been tested and the results contraindicative to further evaluation, or never advanced beyond the concept or preliminary testing stages.

Evidence that reduced entanglement. From an analysis on ropes retrieved from entangled whales off eastern North America, Knowlton et al (2016) recorded that whales of larger body size tended to be entangled in ropes of higher breaking strength, suggesting that whales can break free of ropes with reduced breaking strength. This finding provides encouragement for pursuing techniques that make vertical lines weaker, at least where they can be fished practically. In contrast to the weak links currently mandated for use by the US Government, this study seems to indicate that the pattern may result when more than one portion of the rope has reduced breaking strength. After nearly two decades since weak links became regulated, it is still unclear whether or not they function as intended. Entangled whales have been observed carrying weak links, suggesting they did not achieve their intended objective, however it is just as likely that they may have helped avoid more entanglements. What is know is that over time fishers have transitioned from using natural fiber ropes to plastic ones that have higher breaking strengths (Knowlton et al 2016), and this might help explain why entanglements of North Atlantic right whales show an increasing trend towards incidence and severity despite many years of mandated fishing modifications (Pace et al, 2015).

Any examples that have shown it to work as a deterrent? No.

Is there any basis for continuing to consider implementation of this technique or to carry out further investigation of it? Yes. The recent study by Knowlton et al (2016) as well as broad interest in experimenting with reduced breaking strength ropes by fishermen in Maine and Massachusetts suggest this technique has potential to become a practical change to fishing gear that would reduce the incidence and severity of whale entanglements. It represents a relatively low-cost measure that likely will produce few if any difficult challenges for fishers to implement.

In the case of lipid soluble rope, patent searches and an evaluation of analogous medical suture materials do not suggest that this method shows promise. Medical sutures are water soluble. Galvanic releases, however, could have two possible uses. First, they might secure vertical lines at or close to bottom gear until releasing them for hauling (discussed under "Submerged endlines"). It is inconceivable that a mechanism for releasing pots at a pre-set time could work reliably given the influence of temperature on the rate at which the metal dissolves, and circumstances such as inclement weather or rough sea conditions would prevent fishers from returning to their gear at pre-set times. Nonetheless, if the duration that vertical lines occur in most of the water column could be reduced, whale encounters might also be reduced significantly. Second, fishers could attach releases along parts of their gear in order to reduce the time during which a whale would be entangled and carry trailing gear, a source of drag that can compromise the health of entangled whales. Of course, this would require their replacement after one or more sets depending on the release time. Using galvanic releases for this purpose would not solve the need for quick release, and many whales drown after becoming entangled because they either cannot or do not swim away with the gear in which they became entangled. Therefore, in some cases these releases would only release line well after whales had already perished or their health already irreversibly compromised by becoming tangled in fishing gear.

The performance of time-tension line cutters (TTLCs) and buoy-line cutters were studied in lab and field trials, and generally functioned 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 generally would be set longer than typical hauling duration so as not to release during that procedure. They might therefore reduce drowning in cases where whales were otherwise unable to shed heavy bottom gear in deep water, the weight of which would prevent them from surfacing for air. This may make them most applicable for use in heavier off-shore gear that use multiple traps, or with anchored gear. One concern about TTLCs is that if they work as intended, longer trailing lines could occur on entangled animals more frequently than would ordinarily be the case because they would have caused the lint to which they were attached to part. Longer lines, which can help teams to disentangle whales, also have the potential to result in more wraps following the initial entanglement. There is simply insufficient knowledge or data to evaluate whether either of these scenarios would occur using TTLCs. The buoy line trigger device was invented to deter baleen entanglements. It assumes that an endline passing through a whale's mouth would eventually slide through the baleen and come into contact with 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 that end up involving the buoy end of vertical line. It may be that in many instances lines become entangled in baleen before the full length of the line passes through the mouth. For all these reasons, there is little support at this time for supporting these devices as potential entanglement mitigation options.

Trials of the buoy line messenger system did produce some encouraging results, although one of the major concerns had to do with 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 fishers, it is a technique worth further investigation.

Species/taxa specificity. A combination of large body size and an energetic physical response to the sensation of being entangled are traits of species and individual whales that will more likely assist parting of ropes and nets. In the Knowlton et al (2016) study, Minke and younger Right whales, with their smaller body size, tended to be observed in ropes of lower breaking strength, and the authors concluded that any caught in larger diameter ropes would be more likely to die as a result of the entanglement, such as by drowning while anchored to the gear. There is also the possibility that behavioral responses to entanglement may vary widely even within species and populations.

Under what circumstances would it be most effective? Weak links can be a relatively low cost method, so if effective in helping to release entangled whales they may be particularly appropriate in small-scale, non-industrial fisheries. It is difficult to imagine weak portions of gear incorporated into heavier, off-shore gear, such as the long strings of crustacean pots fished along the eastern edge of North America's continental slope, where currents frequently top 2 knots and fishing depths reach 300m. In these fisheries, other techniques such as submerged vertical lines may be more appropriate.

Where could experiment be easily done? Weaker ropes have been tested already in Maine (Consortium for Wildlife Bycatch Reduction 2007, 2009) and newer prototypes are currently being tested in Maine and Massachusetts. These trials focus on evaluating the ropes from the standpoint of fishing practicality, and less on how effectively they facilitate the release of entangled whales. Long term monitoring of the use of weakened portions of gear can provide an indication of how well they function as intended. Physical testing with a model flipper can help provide insights however it would only apply to situations in which the initial contact point between the whale and a rope is at the flipper. In the meantime, researchers at the New England Aquarium and Duke University are using a computer model to compare the outcome of whale-gear encounters with ropes of variable breaking strengths.

Actual or potential downsides. Most of these devices focus on severing buoy lines. In the absence of buoy markers to identify the presence of gear, this technique could lead to more lost gear or other fishers setting gear on top of unmarked sets. On the other hand, if cutting devices functioned relatively soon after the encounter, this could prevent a whale from carrying off gear and thus make it more likely that a fisher would retrieve gear in which the buoy was no longer present because it remained in the location in which it was originally set.

Research gaps/priorities. Weak rope prototypes should be produced and tested using design ideas that emerge from consultation between fishers, engineers, and rope manufacturers. Evaluations of these prototypes should be carried out in the lab as well as with fishermen, and include small-scale gillnet and pot fisheries in places such as mid-coast Brazil where whale entanglements (of humpbacks) commonly occur. Where data are available, it would be informative to analyze historical data on entanglement rates before and after the introduction of plastic polymer ropes to see if whale entanglement rates differ when controlling for other variables. Measurements of the loads experienced with ropes used in fishing and aquaculture gear, and FAD mooring lines, should be taken to identify where and under what situations weaker lines might be practical. Modeling experiments should examine the likelihood that rope parting methods can help release entangled whales.

In coming up with a new rope design, there is a need to identify differences in loading condition on a rope when an entangled whale interacts with it versus that when it is being fished. A hauler might be expected to concentrate the pull force at the hauler (acting as a fulcrum), whereas an entangled whale would spread out that force over a larger area of the rope because it becomes wrapped over the animal's body. Rope construction components that might be modified individually or in combination to produce a "whale-safe" rope should consider the material used, rope architecture based on different possible molecular configurations, the production process, and construction.

DISCUSSION

No single modification to fishing gear or practices will necessarily be appropriate across an entire fishery nor, for that matter, throughout the range of large whales and where they overlap with fishing and aquaculture. This is because of differences between gear types and variability within them, including how they are used or configured. Fishermen use different types of rope, have variable deck size and hauling machinery, work different fishing grounds that vary considerably in terms of depth, bottom topography, currents, tides, etc., target different catch species, interact with different whale species and populations, and have varying degrees of access to capital for modifying their gear or operations. Although these techniques generally apply to single components of an entire gear set, the result of any changes made have the possibility of increasing entanglement risk from other gear components or the set as a whole. For example, line tension might increase the possibility that a whale can break the line, however it might also cause more severe injuries. Gear components are attached to one another and act in tandem, not in isolation; it is therefore important to pay attention to how change in one part of the system affects not just the physical characteristics of that gear component but the overall system. Modifications therefore need to be evaluated by considering the net effect on whales and fishers alike.

Modifications to fishing gear or practices can also have different impacts depending on the species of whale. For example, the more “playful” behaviors of humpback whales would discourage the development of gear that might attract them, whereas those modifications might help other species avoid gear.

Generally lacking is any evidence from structured experiments or monitoring of entanglements that convincingly show that any of these techniques result in reduced incidence or severity of whale entanglements. Entanglements are rarely observed and achieving sufficient sample size to safely test gear modifications on large whales is a rarity. Included above therefore are suggestions for experiments that can advance scientific evaluation of various techniques. Furthermore, it will be useful to have gear marking so that we can understand the relative risk of specific gear types and modifications, and to develop advanced computer modeling techniques as a platform for simulating encounters between whales and gear.

Group Recommendations

Appendix 4 lists General Recommendations that emerged from workshop participants, including ones presented to the IWC.

Entanglement Scenarios

Support from this project was also provided to refine a computer model developed by the Bycatch Consortium with Dr. Laurens Howle for modeling whale entanglement events. Given that controlled at-sea tests are difficult, if not often impossible, to carry out with large whales, the model was developed as a way to evaluate potential entanglement prevention techniques. A report on this component of the project will be included in a subsequent report to NMFS, using a publication that is undergoing revision for submission to *Marine Mammal Science*.

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Appendix 1
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ADDITIONAL REFERENCE TO ADD TO THIS LIST FROM BYCATCH CONSORTIUM DATABASE:

- Early IWC references (Denmark 1993 with data for Greenland; Iceland 1991, Scotland 1997)
- A SEAMAM doc that has a possible interaction in Thailand
- Mace et al 1999 from the French Mediterranean.

Appendix 2

Global Assessment of Large Whale Entanglement and Bycatch Reduction in Fishing and Aquaculture Gear Agenda

Workshop: Global Assessment of Large Whale Entanglement and Bycatch Reduction in Fishing and Aquaculture Gear
Sheraton Portsmouth Harborside Hotel, Portsmouth, New Hampshire, USA
May 23-26, 2016

Conveners: New England Aquarium, Consortium for Wildlife Bycatch Reduction, NOAA, International Whaling Commission

Overview
Entanglements of baleen whales in fishing and aquaculture gear are a global phenomenon, and a major threat to the survival and recovery of several species and populations. Although the problem is not new, we have made little, if any, progress in identifying solutions that have been shown conclusively to prevent either the incidence or severity of these entanglements, including ones that do not affect the commercial viability of the fisheries that interact with these species.

Over the past several years, some fishermen and researchers have evaluated the potential of modified fishing techniques for preventing whale entanglements. Governments have also implemented regulations in direct response to this threat. In order to make progress on finding practical solutions, we are convening a workshop to review the current status of research on techniques for preventing baleen whale entanglements, and identify research priorities, focusing primarily on what we have learned from studies carried out to date.

The workshop will primarily consider fixed fishing gear and aquaculture. A recent workshop focused specifically on longlines and marine mammal interactions (*see* Werner et al, 2015, ICES JMS 72(5), 1576–1586). Also, although obviously solutions need to consider legal, political, social, cultural, psychological, economic, and policy considerations that may come up during the workshop, its focus is directed at understanding the technical efficacy and potential of different prevention techniques.

The final day of the workshop will also focus on reviewing what we have learned from whale disentanglements, how we can promote improved data collection for characterizing the problem, and additional topics of special interest to the IWC.

Contact
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New England Aquarium (twerner@neaq.org; 1-617-226-2137)

Workshop Agenda

WORKSHOP EVE

18:00 – 19:30
Icebreaker – *Two-Fifty Market*, next to the Lobby of the Portsmouth Sheraton Hotel

[Dinner on your own]

WORKSHOP DAY 1
Roberts Room, Portsmouth Sheraton Hotel

8:00 – 9:00
Breakfast in Roberts Room of Hotel

9:00–9:15
Welcome and Introductions

Theme: WHALE ENTANGLEMENT PROBLEM

9:15-9:55
Overview: Scale of the Problem –K. McClellan/T. Werner/D. Mattila

Theme: VISUAL DETERRENTS

9:55-10:15
Behavioral responses of Rorqual whales (Balaenopteridae) to experimental fishing gear in a coastal environment – B. Kot

10:15 – 10:35
Cetacean sensory systems and visual foraging ecology of right whales – J. Fasick

10:35 – 10:55
North Atlantic Right whale behavioral responses to rope color – S. Kraus

10:55 -11:20 **Break**

Theme: ACOUSTIC DETERRENTS

11:20 – 11:40
Entanglement of migrating whales down under: the search of an effective mitigation strategy – R. Harcourt/V. Pirotta / A. Grech/I. Jonsen/D. Slip/V. Peddemors

11:40 – 12:00
Auditory processing in baleen whales and acoustic deterrence – P. Tyack

12:00 – 12:20
Discussion of morning session

12:20 – 13:30 **Lunch**

Theme: ROPE-LESS FISHING

13:30-13:50
Acoustic release technology and alternatives for setting and accessing submerged head-gear of lobster traps - the New South Wales (Australia) experience– G. Liggins/S. Westley

13:50 – 14:00
Research and testing of a rope-less fishing prototype for the offshore Gulf of Maine lobster pot fishery – J. Partan/K. Ball/T. Werner

Theme: OTHER GEAR MODIFICATIONS

14:00 – 14:20
Ropes and whales – A. Knowlton/ T. Werner/S. Kraus

14:20-14:40
Evaluation of a prototype "weak link rope" in Cape Cod Bay – J. Haviland

14:40 – 15:00
Lines, flippers, and trawls – K. Baldwin/B. Brickett

15:00 – 15:30 **Break** *[Demo of Desert Star Acoustic Release System – M. Flagg]*

Theme: TIME-AREA CLOSURES/QUOTAS

15:30 – 15:50
Reducing entanglement rates of humpback whales off Western Australia using spatio-temporal specific gear modifications – J. How

Theme: REGIONAL CASE STUDIES

15:50 – 16:10

U.S. east coast regulatory measures for large whale entanglements – D. Morin, GARFO, NMFS

16:10 – 16:30
Maine lobstermen working to reduce North Atlantic Right whale entanglements – P. McCarron, K. Porter

16:30 – 16:50
Response of fishermen to whale entanglements in Abrolhos Bank – M. Marcondes

16:50 – 17:10
Mitigating whale entanglement in the bather protection nets on the east coast of South Africa – M. Reade

17:10 – 17:30
Fishermen engagement and response to reducing large whale entanglement threat in US North Pacific – Ed Lyman

17:30
Greenland Case Study – N. Levermann

17:50 **Adjourn**

18:30
Group dinner – The Portsmouth Brewery, 56 Market Street (Tel. 603-431-1115)

WORKSHOP DAY 2
Roberts Room

8:00 – 9:00
Breakfast in Roberts Room of Hotel

9:00-9:10
Overview of agenda for the next two days

9:10 -9:30
Display and discuss deterrents

9:30 – 9:45
Assignments for breakout groups

10:00-12:30
Breakout Groups

12:30 – 13:30 **Lunch [meet with facilitators]**

13:30 – 15:30
Breakout Groups continued

15:30 **Break**

16:00 –RECONVENE

17:30
Preparation of Reports (written and oral)

[Dinner on your own]

WORKSHOP DAY 3
Roberts Room

8:00 – 9:00
Breakfast in Roberts Room of Hotel

9:00-9:10
Daily orientation

9:10-10:30
Complete group reports

10:30 **Break**

11:00-12:30
Breakout group presentations and discussions

12:30-13:30 **Lunch**

13:30-14:30
Breakout group presentations and discussions

15:00
Revise Recommendations

16:30 **Adjourn**

[Dinner on your own]

WORKSHOP DAY 4

"IWC Day"

1. OPENING REMARKS
2. APPOINT CHAIR AND RAPPORTEURS
3. AVAILABLE DOCUMENTS
4. DATA COLLECTION
    - 4.1. Update from FAO technical meeting with opportunity to recommend
    - 4.2. Gear marking – Goals and feasibility globally?
    - 4.3. Disentanglement – what is its role in informing prevention?
        - 4.3.1. Mitigating impacts
        - 4.3.2. Gathering data
        - 4.3.3. Necessary step for awareness?
    - 4.4. International coordination on data collection
        - 4.4.1. Proposed IWC global entanglement database, are National Progress Reports enough?
        - 4.4.2. Recommendations for data collection and coordination
        - 4.4.3. From entanglement response networks
        - 4.4.4. From fisheries observer programs?

5. ALDFG/MARINE DEBRIS
    - 5.1. What do we know about the relative risk from actively fished versus ALDFG and other marine debris

6. GEAR CHARACTERIZATION?
    - 6.1. Are FAO categorizations sufficient?
    - 6.2. Further categorizations (e.g. surface, midwater, bottom)?

7. IWC – ROLE AND RECOMMENDATIONS
    - 7.1. Relevant, feasible recommendations for fishing gear or practices from the first three days
    - 7.2. Promising research to recommend:
        - 7.2.1. Relevant to fishing gear or practices
        - 7.2.2. Relevant to understanding the whales' role in entanglement and prevention
    - 7.3. Current and possible future IWC initiatives (e.g. capacity building, outreach)
    - 7.4. Engagement with other IGOs

APPENDIX 3

WHALE ENTANGLEMENT PREVENTION BIBLIOGRAPHY

PHYSICAL FISHING GEAR MODIFICATIONS

High Tension Rope

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Appendix 3

Acoustic Startle Response
P. Tyack

All mammals tested have a reflex response to sounds that rise to more than 80-90 dB above the threshold of hearing within 15-20 msec (Yeomans & Frankland 1995). This acoustic startle response (ASR) has been studied in grey seals (Goetz & Janik 2011), which respond by avoiding the sound source. Seals sensitize to these stimuli to the point that they avoid food sources nearby. This has suggested the use of ASR stimuli as deterrents to prevent seals from taking fish from aquaculture facilities. Goetz & Janik (2015) studied the use of an ASR stimulus at a fish farm, and showed that seal numbers dropped sharply within 250 m during sound exposure. These stimuli were designed to reduce avoidance responses of harbor porpoises. Even though porpoises are known to be more sensitive than seals to high frequency sounds, they did not show significant responses to the lower frequency ASR stimulus.

Goetz & Janik have been funded to study acoustic startle responses of humpback whales. This research can improve our understanding of hearing in these whales and of the stimulus characteristics required to stimulate ASR in baleen whales.

Harcourt et al. (2014) and Pirotta et al. (2015) did not detect avoidance responses of humpback whales migrating past pingers with source levels of 135 and ??? dB re 1 μPa. However, several studies on the effects of industrial sounds (Malme et al. 1983), sonar (Goldbogen et al. 2013) and alerting stimuli (Nowacek et al. 2003) that all involved higher source levels have shown well defined avoidance responses. These suggest that the results showing little avoidance of pingers in baleen whales occurred because these stimuli were not strong enough to elicit avoidance rather than from a more fundamental lack of avoidance.

These observations suggest renewed testing of avoidance responses of baleen whales using stimuli with higher source levels designed to evoke the right level of avoidance to reduce risk of entanglement. In situations where acoustic deterrents mark a hazard, such as a food source, that may be attractive to whales, use of acoustic startle stimuli may reduce the risk of habituation, or, even worse, use of the signal as a dinner bell.

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Appendix 4

General Recommendations from the Global Assessment of Large Whale Entanglement and Bycatch Reduction in Fixed Fishing Gear workshop

CONTEXT

Entanglement in fishing gear is a major global threat to marine mammals including the great whales (all 14 species of baleen whales and the sperm whale). Although monitoring is not systematic for all species and populations, decades of observations demonstrate that entanglement is a global phenomenon occurring everywhere that whales and fishing gear overlap in space and time. Entanglement is not relegated to one gear type, rather it includes: pots, fixed nets, longlines, trawls, weirs, and seine nets, as well as bather protection nets ("shark nets" or "beach nets"), mussel longline aquaculture, and fishing aggregation devices (FADs). It can involve active, abandoned, lost, or discarded fishing gear (ALDFG). Increasing fishing effort and the advent of stronger synthetic ropes have contributed to the entanglement problem. For some species/populations, such as the critically endangered North Atlantic right whale, North Pacific right whale, the Arabian Sea humpback whale, and Western Pacific gray whale, the estimated entanglement rates are unsustainable, pushing some of these species and populations towards extinction if the problem is not addressed.

Entanglements also threaten the livelihoods of fishermen and coastal economies that depend on fisheries revenues. Gear loss or damage caused by whales may require additional outlays for gear repair or replacement, and lost catch. In some areas or regions, whale bycatch can also result in regulators closing fishing grounds temporarily or permanently, and the stigma around high rates of entanglement can generate negative public relations for fishermen and their product in the market place.

There are a number of fishing techniques that have been shown, or have the potential, to reduce bycatch of non-target marine mammals, sea turtles, and seabirds in at least some areas (Werner et al, 2009, 2015), although in the case of whales the few that have been implemented lack conclusive data indicating whether or not they effectively reduce either the incidence or severity of entanglements. Some of these (such as ones that reduce the number or length of ropes in the water column) have received wide support among fishermen, scientists, and regulators based on their expert assessment of their potential to reduce entanglement risk, and are likely to produce their intended benefits. Others (such as acoustic deterrents—e.g., pingers) have not been scientifically demonstrated to be effective for large whales although sometimes they have been marketed as such.

Although the focus of this workshop was on devices and techniques that can be incorporated into fishing gear, it is recognized that switching gear, reducing effort, or spatial-temporal management have a role in managing bycatch of large whales in some situations, and that in some cases alternative types of fishing gear might produce comparable fishing revenues while reducing entanglement risk. The workshop participants stressed that there is no single panacea for large whale entanglements, and recognised that whilst there are lessons to be learned from global examples and great value in international co-operation and information sharing, local problems require local solutions.

When considering bycatch mitigation measures, workshop participants noted that, where possible, the 'ideal' hierarchy for action in descending order should be to: 1) avoid encounters with fishing gear, 2) reduce entanglements in such gear where encounters cannot be avoided, and 3) minimize mortality associated with entanglement when entanglement occurs. This does not imply that actions on all three cannot proceed in parallel, and promising (e.g. simple, cost effective, and effective) actions that enjoy support among fishermen should be encouraged. Within this framework, assessments of the overall cost-benefits of different options (including consideration of user and conservation goals) can help identify priority techniques for testing and implementation.

Workshop participants stressed that any mitigation action should include a commitment to a well-designed and long-term monitoring program to evaluate the effectiveness of the bycatch mitigation over time.

RECOMMENDATIONS

1. Recognizing development and implementation of solutions has lagged behind the increasing threat in many locations and around the globe, the workshop participants **recommend** that governments recognise the importance of the issue and work internationally and nationally to promote an environment that facilitates a more rapid development and testing of methods and implementation and monitoring of mitigation measures. This is especially important as entanglement risk assessment, and the implementation and monitoring of entanglement prevention measures must consider the species'/population full geographic distributions.
2. Given the scope and urgency of this issue, workshop participants strongly **recommend** that inter-governmental organizations and regional fishery management organizations elevate bycatch of whales to the level that spurs these entities to evaluate their data to assess the risk of cetacean bycatch in their fisheries and, where necessary, develop and implement bycatch prevention and mitigation measures.
3. The development and implementation of effective solutions requires full collaboration between fishers and gear technologists, for innovation, development of practical ideas and applications, and scientists for appropriate testing methodology; therefore participants **recommend** that fisheries associations, individual fishers, technologists, scientists, and regulators collaborate to develop, test, and implement whale entanglement prevention techniques. In this regard, the participants also **recommend** that

fishermen and scientists identify test areas (throughout the world) that can optimise evaluation of techniques that can either advance our understanding of or significantly prevent/reduce entanglement. These collaborations should be encouraged and facilitated by national and regional authorities.

4. Recognizing that the fishing sector is central to both the consequences of whale entanglements and the solutions, the workshop participants **recommend** that respected members in the fishing community use their understanding of the urgency and magnitude of the bycatch problem to: (1) communicate the issue within their community, (2) lead the innovation of bycatch reduction measures, and (3) promote socio-economic perspectives of the problem so that appropriate mitigation measures can be implemented that have the greatest probability of achieving long-term use and support within the fishery.
5. Given the scope and urgency of the issue, participants strongly recommend that authorities facilitate the evaluation of bycatch mitigation measures, and expedite any administrative requirements or permits needed to test such mitigation.
6. While structured experiments are the preferred and optimal approach for developing and evaluating bycatch mitigation measures, they are often difficult to conduct; workshop participants suggest that other analytical techniques be considered for such studies, and that evaluation of field work should be augmented by simulation studies and appropriate incorporation of opportunistic information.
7. Given the present lack of sufficient data to understand the frequency and process of entanglement, the workshop **recommends** that nations and scientists make a concerted effort to gather and make available current and historic data on entanglement and to promote frequent exchange of information among fishers, scientists, and policy makers on bycatch mitigation through workshops, websites, and other collaborations.
8. Artisanal fisheries represent the largest sector of global fishers and may be the greatest contributor to cetacean bycatch; therefore, workshop participants **recommend** that nations and scientists assist and engage artisanal fishers in the development and evaluation of prevention measures for their fisheries.

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