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Impacts of Longline and Gillnet Fisheries on Aquatic Biodiversity and Vulnerable Marine Ecosystems

Impacts des pêches à la palangre et au filet maillant sur la biodiversité aquatique et les écosystèmes marins vulnérables

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ABSTRACT

The impacts of longline and gillnet fishing on biodiversity and ecosystems, and known mitigative measures, both from international and Canadian experience, are summarized to support a Canadian Science Advisory Workshop on the topic.

Biodiversity issues are mostly framed as bycatch in the literature.

For longlines, a combination of net-sleeves, weighted mainlines, and bird-scaring lines, supplemented by dyed bait, offal control, and night setting can now be very effective in reducing bird bycatch. Zero-offset circle hooks, the use of fish rather than squid as bait, improved de-hooking protocols, training of practitioners, and fishing in colder water appear reduce turtle bycatch and mortality. Net sleeves appear to reduce marine mammal bycatch, but avoidance of whale concentrations remain the main effective mitigative strategy.

For gillnets, mitigation of bycatch through gear modifications is not as far advanced. Recovery boxes to improve survival of released fish bycatch, and some species-specific net modifications are used regularly in salmon gillnet fisheries. Coloured net panels to deter bird bycatch and acoustic deterrents to dissuade interactions with marine mammals show some promise, but are not widely used. Best strategies to avoid bycatch are management of areas, depths, or times the gear is utilized.

"Ecosystem impacts" are generally interpreted as impacts on habitats. Both pelagic gillnets and longlines have minimal impacts on habitat. Demersal applications of the gear, however, have some demonstrated impacts through entanglement and breakage of bottom features such as corals. The main concerns are with impacts on seamount ecosystems, deep-sea coldwater coral, and sponge communities. The prime mitigation strategy is avoidance of most sensitive areas. International protocols including precautionary management, closed areas, and protection for corals are pending.

"Ghost fishing" by lost gillnets and longlines is also of concern. Improved technology, regulations, and awareness of users is reducing rates of loss and improving recoveries, the only effective mechanisms so far for this problem.

An increased broader public concern has helped to drive many changes. Healthy discourse with conflicting points of view and collaborative development of policies and practices by managers, users, and other interested parties appear to be key elements for success for improved responsibility and sustainability of fisheries.

RÉSUMÉ

Les impacts des pêches à la palangre et au filet maillant sur la biodiversité et les écosystèmes, ainsi que les mesures d'atténuation connues, à la lumière de l'expérience internationale et canadienne, sont résumés dans le présent rapport en appui à la tenue d'un atelier de consultation scientifique sur le sujet.

Les enjeux associés à la biodiversité les plus souvent cités dans les publications scientifiques concernent les prises accessoires.

Relativement aux palangres, en combinant plusieurs mesures, notamment les manchons coniques placés sur les filets, les lignes lestées ainsi que les lignes visant à effaroucher les oiseaux, en plus de la coloration des appâts, du contrôle des abats et de l'installation des filets durant la nuit, on arrive à réduire efficacement les prises accessoires d'oiseaux. Les hameçons circulaires « zero-offset », l'utilisation de poissons plutôt que de calmars comme appâts, les protocoles améliorés de décrochage, la formation des intervenants et la pêche dans des eaux plus froides semblent avoir permis de réduire les prises accessoires et la mortalité des tortues. Les manchons coniques semblent avoir réduit les prises accessoires de mammifères marins, mais le fait d'éviter les concentrations de baleines demeure la meilleure stratégie d'atténuation.

Relativement aux filets maillants, l'atténuation des prises accessoires par les modifications apportées aux engins n'a pas autant progressé. Les boîtes de récupération visant à améliorer la survie des poissons relâchés et certaines modifications apportées à des filets réservés à une espèce sont des mesures appliquées régulièrement pour la pêche au filet maillant du saumon. Les panneaux de couleur visant à prévenir les prises accessoires d'oiseaux ainsi que les moyens de dissuasion acoustiques visant à décourager les interactions avec les mammifères marins semblent des moyens prometteurs, mais leur usage n'est pas très répandu. La gestion des zones, des profondeurs ou des périodes d'utilisation des engins forment la meilleure stratégie pour éviter les prises accessoires.

Les « impacts sur les écosystèmes » sont généralement interprétés comme étant des impacts sur les habitats. Les filets maillants et les palangres pélagiques ont des effets minimes sur l'habitat. Cependant, on a démontré certains effets associés aux applications de fond des engins causés par l'enchevêtrement et le bris de caractéristiques de la faune benthique, notamment les coraux. Les principales préoccupations portent sur les écosystèmes des monts sous-marins, les coraux d'eaux froides en eau profonde et les communautés d'éponges. La principale stratégie d'atténuation consiste à éviter les zones sensibles. On disposera sous peu de protocoles internationaux visant notamment la gestion par l'approche de précaution, les fermetures de zones et la protection des coraux.

La pêche fantôme (captures par les filets maillants et les palangres perdus) est également une source de préoccupation. Des technologies améliorées, la réglementation et la sensibilisation des utilisateurs permettent de diminuer le taux de perte et d'améliorer la récupération des engins, et c'est le seul moyen efficace appliqué à ce jour pour régler ce problème.

La sensibilisation d'un public plus vaste a également contribué à susciter des changements. Un discours équilibré comportant des points de vue divergents et l'élaboration de politiques et de pratiques en collaboration avec les gestionnaires, les utilisateurs et les autres parties intéressées semblent être des éléments essentiels pour arriver à un sentiment de responsabilité accrue et à la durabilité des pêches.

EXECUTIVE SUMMARY

This report compiles and summarizes knowledge on the impacts of longline and gillnet fishing on biodiversity and ecosystems, and their mitigative measures. This information will support a Canadian Science Advisory Workshop on the topic. The material in this report describes both international and Canadian experience, including impacts that may not occur in Canadian fisheries.

In the literature, biodiversity impacts are largely framed within the question of fishing bycatch, though some discussion also exists on impacts through changes in the species targeted by the fisheries and impacts on species not caught but influenced by the fishing activity (for example, attracted by fish discards or suffering collateral damage). Compared with other fishing gear, both gillnets and longlines are considered to have high biodiversity impacts through bycatch, with demersal longlines showing a somewhat lower impact (Chuanpagdee *et. al*., 2003).

The FAO is the main international body to provide guidance on bycatch mitigation, with a principal focus on seabird bycatch in longline fisheries. A 2008 review workshop on this issue suggests that mitigation mechanisms can now be very effective in reducing bird bycatch in most situations, through a combination primarily of net-sleeves on the hooks, weighted mainlines, and bird-scaring lines, supplemented by dyed bait, offal control, and some other practices. Night setting is a measure that is particularly effective on the Canadian Atlantic coast.

Control of turtle bycatch on longlines has been largely led by the World Wildlife Fund and the Inter-American Tropical Tuna Commission (IATTC). The introduction of zero-offset circle hooks, reduced use of squid as bait, improved de-hooking protocols, and training of practitioners appear to be the most effective mitigation tools, showing significant success.

Only net sleeves appear to be useful for reducing marine mammal bycatch on longlines, with avoidance of whale concentrations remaining the main effective mitigative strategy to avoid bycatch and depredation by this group.

Mitigation of bycatch in gillnets through gear modifications, on the other hand, is not far advanced. While mesh size affords this gear some size selectivity, species selectivity is very poor. The main mitigative strategies to avoid bycatch are management of areas, depths, or times the gear is utilized. For example, unacceptable levels of diverse bycatch of the drift-net squid fishery in the North Pacific led to its eventual prohibition, and prevented the establishment of a similar squid fishery on the coast of British Columbia (McKinnell & Seci, 1998). Coloured net panels to deter bird bycatch and acoustic deterrents to dissuade interactions with marine mammals show some promise and application, but are not widely used nor without controversy. Mechanisms to improve survival of fish bycatch, including modifications of mesh material and panel construction, shorter soak times, user training, and recovery boxes have shown promise on the BC coast (Buchanan et al., 2002; DFO, 2002), and are now used regularly in salmon gillnet and seine fisheries in BC and Washington State (WDFW, 2009).

"Ecosystem impacts" of gillnets and longlines are generally interpreted in the literature as impacts on habitats, though many of the habitats of particular concern, including Vulnerable Marine Ecosystems (VME), are at least partially of biogenic origin (i.e. benthic ecosystems). Habitats of particular concern are those that provide the basis of a particularly diverse and/or unique set of associated fauna, are easily damaged, and/or take a very long time to recover

from impacts. VME are considered a particularly significant subset of these sensitive habitats/ecosystems of international concern, but are not yet very clearly defined.

Both pelagic gillnets and longlines are considered to have minimal impacts on habitat. Demersal applications of the gear, however, have demonstrated impacts through entanglement and breakage of bottom features such as corals – though considerably less than that of dredges or bottom trawls. The main concerns in the literature with regards to VMEs are the impact of gillnet and longline fisheries on seamount ecosystems and on deep-sea coldwater coral and sponge communities. The prime mitigation strategy appears to be avoidance of most sensitive areas, in part through Marine Protected Areas and area closures. International protocols including precautionary management, closed areas, and protection for corals are pending. Concern also exists over abandoned gillnets and longlines, that unlike active gear, continue to affect ecosystems unattended. Reduction of loss and discarding of gear through improved technology and regulations, as well as improved awareness of users, appears to be the only effective mechanism so far for this problem.

Management solutions to gear impacts include area and time closures and protocols on how the gear is used, but considerable emphasis is now placed on Ecosystem Approaches to Fisheries (formerly Ecosystem Based Management) that integrate concerns for sustainability of target species stocks with sustainability of other elements of the species' ecosystem.

Driving forces behind the changes in modern fisheries management are not limited to the maximization of sustainable resource extraction. Rather, an increased broader public concern for sustainability of a variety of ecosystem elements for other uses, non-wasteful use of resources, and recognition of the inherent right of other organisms to survive, has helped to drive many changes. For example, both "wasteful fishing practices" that could affect sustainability and "iconic species" are factors in the evolution of the bycatch question, but concerns for iconic species dominate. These are species with a high public profile, many at risk of extinction, but not necessarily species of immediate concern to the sustainability of the fisheries resource. While the interplay of these forces may at times be raucous, their integration is paving the way to sustainable fisheries of the future. Healthy discourse with conflicting points of view and collaborative development of policies and practices by managers, users, and other interested parties appear to be key elements for success. New policy developments will no doubt need to reflect this.

INTRODUCTION

Canada has an international obligation, under United Nations General Assembly Resolution 61/105 and the Northwest Atlantic Fisheries Organization (NAFO) to manage its fisheries sustainably and to protect biodiversity and vulnerable marine ecosystems from destructive fishing practices. This obligation has highlighted the need to assess the effects of Canada's existing and exploratory fishing activities and the mitigation of identified impacts. This report is a compilation and summary of existing international and domestic literature on the impacts of gillnet and longline fisheries on biodiversity and vulnerable marine ecosystems, prepared for the Department of Fisheries and Oceans Canada (DFO). This will inform the participants at an upcoming 2009 Canadian Science Advisory Secretariat (CSAS) workshop and will guide the development of Canadian policies that address the effects of these fishing gears on marine habitats and aquatic biodiversity.

Commercial fishing has a demonstrated impact on marine ecosystems, determined by factors such as gear type, gear design, timing, duration and frequency of use, as well as fisher competence and knowledge (Revill 2003). Impacts include habitat degradation or destruction, population declines and collapses from over- fishing, decline of populations of non-target species due to bycatch or other ecosystem impacts, and shifts in species compositions (Hughes *et al.* 2005; Environment Canada 1996). Evidence of these impacts has led to an increasing recognition of the need for more sustainable fishing practices and the need for new and updated legislation. Driving this need are two main factors: i) reduced stocks of target species, leading to industry lobbies and ii) impacts on non-target iconic species, ecosystems, or local stocks that create a broader public perception of fisheries impacts and related lobbying. Both drivers lead to formal and informal investigation, a sometimes raucous discourse, and both convergent and divergent mitigative strategies. This report investigates the current status of this field, as reflected in the literature, focussing on the identified gear types. However, while recognizing the interplay of the driving forces behind the development of changing policies and practices, we found that it was beyond the abilities of the current review to differentiate in detail these separate influences.

BIODIVERSITY – A WORKING DEFINITION & PRINCIPAL ISSUES

Biodiversity is defined as “the variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (Biodiversity Convention Office 1995).

Other than impacts through the removal of the target species, “bycatch” is generally considered the principal impact of fisheries on biodiversity. The Food and Agricultural Organization of the United Nations (FAO) define bycatch as the “part of a catch taken incidentally in addition to the target species”. Gilman *et al.* (2008) state that “bycatch can alter biodiversity by removing top predators and prey species at unsustainable levels.” This becomes a particularly visible conservation problem when iconic species, such as sharks, albatrosses and sea turtles, that are threatened with extinction, are major bycatch species – even if they are not keystone species in an ecosystem. To protect these species and the biodiversity of the aquatic ecosystem, several mitigation solutions are being explored in the global fishing industry – both through gear modifications and management strategies.

In a 2003 publication, *Environmental Indicators*, habitat loss was identified as “the key threat to biodiversity in Canada” (Environment Canada 2003). This is important to the Canadian and global fishing industry since fishing gear has been documented to have significant detrimental impacts on habitats (reviewed by Rice 2006). However, habitat impacts are generally considered separately from biodiversity impacts in the fisheries literature, though a move to label them as “ecosystem impacts” signals recognition of the interplay between habitat and biodiversity that Rice (2006) and others refer to.

Marine protected areas and non-fishing reserves are being explored and implemented in various parts of the world “as a key tool in efforts to preserve biodiversity” (Environment Canada 2003). This is a strategy that is generally geographically focussed, but more complete as an integrated protection from fishing impacts in an area.

VULNERABLE MARINE ECOSYSTEMS – A WORKING DEFINITION & PRINCIPAL ISSUES

Vulnerable marine ecosystems (VME) are of particular interest for protection from the effects of fishing within the concept of human activities that allow for sustainable environmental protection. The FAO defines VME as:

“areas that are easily disturbed by human activities, and are slow to recover, or which will never recover. Marine ecosystems may be easily disturbed if: (1) they are characterised by low-levels of natural disturbance and / or low levels of natural mortality; (2) component species are fragile and are easily killed, damaged or structurally or biologically altered by human impacts, in this case mechanical disturbance by fishing gear; (3) distribution is spatially fragmented with patches of suitable habitat that are small in area and "rare" in comparison to the overall area of seabed; or (4) important ecosystem functions are disrupted or degraded."

Examples of VME include warm- and cold-water coral reefs, sponge fields, seep and vent communities, submerged edges and slopes, seamounts, polymetallic nodes, and trenches and canyons.

"Sensitive habitats" is a similar term to VME, defined as habitats that "are easily adversely affected by human activity and/or if affected are expected only to recover over a very long period, or not at all" (UNGA 2006). Examples of sensitive habitats include seapen fields, burrowing megafauna communities, reefs and oyster beds (UNGA 2006).

"Sensitive habitats" have been described primarily for shallow waters between 0 and 50 metres depth, though some in depths of 200 metres or more are also included. Descriptions of VME, in contrast, focus largely on deep-sea situations. For example, sponge field samples have been collected as far down as 6,000 metres (UNGA 2006), and deep-sea mounts and oceanic trenches are, by definition, deep-sea phenomena. However, there is clearly overlap in the two concepts, and in this review we will deal with both.

The ecosystems under consideration have important biodiversity functions, often with high levels of species diversity and endemism (UNGA 2006) that have significant impacts beyond their immediate borders. For example, as Smith (no date) points out, seamounts and oceanic islands enhance productivity, and provide a unique deep-sea environment for fishes and invertebrates that are not found in the open ocean. The high-profile structures distinctive of these areas provide a large diversity of habitats, resulting in a high diversity of species assemblages. For example, over 800 species have been observed living on or around deep-sea coral reefs, and species richness is estimated to twice as high in sponge fields as in the surrounding environment (UNGA 2006).

The deep ocean is particularly rich in recognized VME, therefore, there is great concern that as fishing extends into this realm, and irreversible impacts may be around the corner. Accessible fish stocks in shallower water have continued to decline, but the demand for fish continues to climb. Fishing fleets thus are exploring new territories, assisted by more technological sophistication, and commercial fisheries are expanding further offshore into deeper waters (Morato *et al.* 2006; UNGA 2006). This is particularly worrisome, as deep-sea fisheries focus first on areas of high concentrations of fish, generally coincident with high species diversity and VME such as seamounts, cold water coral reefs and ridges and trenches (UNGA 2006). The species found in these deep water ecosystems generally have "high longevity, slow growth, late maturity, and low fecundity" (Morato *et al.* 2006; Rogers 2004; FAO 2008a), which makes them particularly vulnerable to exploitation and slow to recover. Species found in VME may also not move readily between habitat patches, nor recruit well from other sources (UNGA 2006), thus making the assemblages particularly sensitive to localized perturbations.

Rice (2006) reviewed the impacts of mobile fishing gear on seafloor habitats and concluded that fishing gear can "damage/reduce habitat structure and complexity, reduce/remove major habitat features and can alter seafloor structure." Active gears such as trawls and dredges have the greatest impacts, but passive gear such as demersal gillnets and longlines[1] can also have an impact, for example, through entanglement with branching corals (High 1998). This impact on habitat structure affects other species that use the structures and subsequently impacts the biodiversity of the ecosystem.

GILLNET AND LONGLINE FISHING GEAR

Gillnets and longlines are passive net and hook gears, respectively[2]. Net and hook gears are fishing methods or technologies that have been used throughout history, and together with fish traps and weirs were the main methods used to catch fish before the industrial revolution (Hovgård and Lassen 2000). Active fishing gear, such as trawls and seines, aided by substantial technological innovation, now dominate the industrial fishing industry. As Hovgård and Lassen (2000) point out, however, gillnets and longlines (also aided by technological innovations in materials and electronics) continue to be popular because of certain advantages:

- They are relatively cheap to purchase and use
- They are technologically simple and easy to mend
- They require little in the way of equipment on board the fishing vessels (depending on the level of sophistication)
- They may be set in areas with difficult access or bottom conditions

Gillnets and longlines are used globally, including common use in artisanal fisheries. They are an economical choice for both artisanal and industrial fisheries "targeting large and expensive fish species that are thinly distributed, e.g. tuna, salmon and halibut" (Hovgård and Lassen 2000). In Canada, gillnet and longline fisheries are valued at over $191 million (Fuller *et al.* 2008).
These gear types are also important in research assessing stock abundances and biodiversity in areas with difficult bottoms or access where trawl surveys cannot be conducted (Hovgård and Lassen 2000) Husebo *et al.* (2002), for example, used gillnets and longlines to investigate the importance of cold-water *Lophelia*-reefs for fish. The gear can be relatively benign in its impacts on habitat, but it is not inherently species specific, and bycatch of non-target species is problematic. The resistance of materials currently used in manufacture of this gear also creates problems with "ghost-fishing,"[3] as lost gear continues to fish unattended.

BIODIVERSITY & ECOSYSTEMS IMPACTS

The terminology of "biodiversity and ecosystem impacts" of fisheries is relatively not very common, possibly reflecting a conceptual overlap in the two issues. In an overall sense, the issues are more commonly lumped together as "environmental" impacts, with subdivisions that relate to biodiversity and ecosystem-level impacts. "Biodiversity", while affected at the ecosystem level by changes in the abundance of the target species and possibly at the species level by shifts in growth-determination or behaviour-determination genetic biodiversity, is most commonly framed as a bycatch problem. "Ecosystem" impacts are generally framed as "habitat" impacts, with a distinction at times (though rarely) between biogenic and non-biogenic habitats. While substantial literature exists on the concepts of biodiversity and ecosystem impacts, a profile of literature detected by the Aquatic Sciences and Fisheries Abstracts (ASFA) illustrates the terminology and framing of the issues:

[1] See appendix A for description of gear types
[2] See appendix A for descriptions used for this review
[3] See appendix B for glossary of terms

Table 1: Profile of literature with keywords related to "biodiversity" and "ecosystem" impacts in fisheries in Aquatic Sciences and Fisheries Abstract database

search terms	ASFA keyword "hits"
fisheries & biodiversity	2589
fisheries & biodiversity & impact	553
fish & biodiversity	3562
gillnet & biodiversity	16
longline & biodiversity	31
fisheries & ecosystem	15446
fisheries & ecosystem& impact	2599
gillnet & ecosystem	71
longline & ecosystem	126
bycatch	2099
fisheries & bycatch	1863
gillnet & bycatch	122
longline & bycatch	354
habitat	73489
fisheries & habitat	13702
fisheries & habitat & impact	2010
gillnet & habitat	85
longline & habitat	133

Within the concept of “environmental” impacts, several reviews distinguish fisheries impacts. Amongst these:

- The Centre for Environment, Fisheries and Aquaculture Science - CEFAS (Revill 2003) classifies environmental impacts of fishing into seven categories as follows: (1) capture of target species of marketable/legal size; (2) capture of target species of non-marketable/sub-legal size; (3) incidental capture of non-target species; (4) benthic habitat damage; (5) effects from lost or abandoned fishing gear; (6) ecosystem change; and (7) incidental mortality.

- Hall (2001) describes ecosystem impacts of fisheries as either direct or indirect. Direct impacts include (1) mortality of target and bycatch species, either through retained catch, collateral direct mortality (for example discards of undersize or unwanted catch), or making individuals more vulnerable to scavengers or predators, (2) increasing the food available to other species by discarding unwanted catch; or (3) disturbing and/or destroying habitats with the fishing gear. Indirect impacts include changes in the abundances of predators, prey and competitors of the target species resulting from reduced abundances of the directly affected species and/or the provision of food through discarding of unwanted catch. For fisheries in a general sense (not specific to gear type), this author indicates that the principal ecosystem impact is to shift the general trophic levels of fisheries down, (Pauly's "Fishing down the foodchain") (Pauly et. al. 1998), ie. "Fisheries are operating at levels that are certainly inefficient and probably beyond those that are prudent if we wish to prevent continuing change in the trophic structure".

- More specifically, Rice (2006) described the impacts of mobile bottom gear on seafloor habitats, species and communities (with some mention of gillnets and longlines) and a report to the United Nations General Assembly (UNGA 2006) deals with national actions on impacts to Vulnerable Marine Ecosystems (VME).

The Ecology Action Centre, Living Oceans Society and Marine Conservation Biology Institute have published a review to "address the ecological impacts of Canadian fishing gear" (Fuller *et al.* 2008), preceded by a study by Chuenpagdee *et al.* (2003) on the perception of fisheries impacts of a mixed group of people working with fisheries at a workshop in the United States. This earlier version of "ecological impact" is divided into "habitat" and "bycatch" categories (see tables 2 and 3 below).

Table 2. Ecological impacts of fishing gears in Atlantic and Pacific Canada as described in Fuller et al. (2008) Ratings are based on expert consultations, available DFO data and reviews of the scientific literature 1 = very low impact, 5 = very high impact

	Habitat		Bycatch					
Gear type	**Corals & Sponges**	**Seabed**	**Inverteb-rates**	**Ground-fish**	**Forage fish**	**Sharks & large pelagics**	**Marine mammals**	**Seabirds**
Bottom Gillnet	4	2	3	5	1	3	3	4
Bottom Longline	4	2	2	5	1	3	3	2
Bottom trawl	5	5	5	5	4	2	2	2
Dredge	5	5	5	4	1	1	1	1
Harpoon	1	1	1	1	1	2	1	1
Hook & Line	2	1	1	4	2	2	2	1
Midwater trawl	1	1	1	4	5	3	2	2
Pelagic longline	1	1	1	2	2	5	4	3
Pot & trap	3	2	3	3	2	1	1	3
Purse seine	1	1	1	2	4	3	2	2

In the current report, we will follow the structure of the literature, but with linkages to the concepts of "biodiversity" and "ecosystem" impacts.

HABITAT IMPACTS

Environmental assessments

Most fisheries are currently exempt from environmental impact assessment (EIA) or strategic environmental assessment (SEA), even in areas where other users of the marine environment, such as the oil and gas industries, must conduct them. More fisheries management bodies, however, are considering these assessments, encouraged by the FAO Code of Conduct for Responsible Fisheries (FAO 1995) (Jennings and Revill 2007) and pressures from NGOs and consumer lobby groups, such as the Marine Stewardship Council. As an example, Article II of CCAMLR mandates an ecological risk assessment for new fisheries, which New Zealand's National Institute of Water & Atmospheric Research Limited

(NEWA) is currently conducting for a proposed longline fishery of the Antarctic Toothfish (*Dissostichus mawsoni*) (Pinkerton *et al.* nd).

Assessing habitat sensitivity and vulnerability

Methods for assessing habitat sensitivity are increasingly well developed, although not yet entirely systematized (Zacharias and Gregr 2005). "Sensitivity" may best be defined as the "inverse of recovery time following a given gear impact" (Jennings and Revill 2007.) Sensitive habitats, therefore, are those habitats that are "easily adversely affected by human activity, and/or if affected, are expected to only recover over a very long period, or not at all" (UNGA 2006). The related concept of "vulnerability", used to describe habitats and ecosystems, is "related to the likelihood that a population, community, or habitat will experience substantial alteration from chronic disturbance, and the likelihood that it would recover and in what time frame" (FAO 2008a).

When discussing or evaluating the vulnerability of a habitat or ecosystem with respect to fishing impacts, all impacts on the variety of components of the habitat need to be evaluated, not just the physical impacts of the fishing gear. It is "the many constituent species and ecological processes that comprise an ecosystem that are directly affected by human activities, not ecosystems" (FAO 2008a), but the synergy of these different components are what defines a functioning ecosystem. Unfortunately, the literature focuses primarily on the direct physical impacts.

Physical impacts of gillnets and longlines

Physical impacts on habitats from gillnet and longline fishing varies and depends on the gear configuration, hauling technique and the habitat substrate (Fuller *et al.* 2008).

Gillnets are set at varying depths in the water column depending on the target species:

- Pelagic gillnets do not touch the seafloor and are therefore considered to have no impact on habitat structures (Fuller *et al.* 2008);

- Demersal or bottom gillnets are anchored to the seafloor, but are considered by some reports to have minimal impacts (Fisheries Agency of Japan 2008.)

In their 2008 report, the Fisheries Agency of Japan describes that the Japanese bottom gillnet fishery in the Emperor Seamount and North Hawaiian Ridge areas, uses gillnet "sections" of 56 net panels, each panel 30m in length. In a single fishing day, 10 sections (about 15 km) are left to fish suspended 70 cm above the sea floor by floats, each panel (30 m in length) being equipped with 7 floats and 5 concrete sinkers weighing about 5kg. The physical effects on bottom ecosystems are thus considered minimum.

Other studies have shown that the impacts of gillnets can alter the seafloor (High 1998). Hourigan *et al.* (2007) report that on the Porcupine Bank in the northeastern Atlantic, anchors and weights that touch the seafloor, such as with bottom gillnets, can impact deep sea coral habitats significantly. Chuenpagdee *et al.* (2003) surveyed the opinions of various stakeholders of fishing issues (including fishers, managers, NGOs, academics) and rated habitat impacts of bottom gillnets as "medium" (see Table 2), but recommended "stringent" management policies including complete prohibitions in ecologically sensitive areas. This recommendation is no doubt also informed by high bycatch rates of gillnets. However, Fuller *et al.* (2008) also surveyed the opinions of Canadian stakeholders on habitat impacts of fishing in a more intensive manner, and ranked the impacts of bottom gillnets as high, behind bottom trawling and only just ahead of dredging.

Longlines, similarly to gillnets, are used as pelagic and demersal versions:

- Pelagic longlines consist of a weighted mainline that hangs horizontally in the water, suspended at intervals from surface buoys. Lines with hooks branch off this mainline. The longline can be deployed at different depths, depending on the species being targeted. A "dropline" is a comparable longline that sits vertically in the water column to take advantage of a more geographically limited fishing opportunity. The weight and lines do not generally touch the bottom, so this method of fishing is considered to have no impact on bottom habitats.

- Demersal longlines consist of a mainline, with component leaders and hooks, that is held in place on the seabed by anchors or weights. These have been shown to have an effect on habitats. While the gear is both fishing and being hauled in, the lines can get entangled in structural components of the habitat. High (1998) reported that "large branching corals can be detached, entangled, and brought up as bycatch by longlines." In Nova Scotia, gorgonian corals have been recorded tangled and snagged in longline gear (Breeze *et al.* 1997), and Mortensen *et al.* (2006) identified direct and indirect impacts of longlines on corals off Canada. A survey of longline bycatch in the Gulf of Alaska and Aleutian Islands "showed *Primnoa* and other coral taxa were caught on 619 of 541,350 hooks fished at 150–900 m depths" (Krieger 2001).

In Norway, a considerable net and longline fishery is active in areas with *Lophelia* cold-water reefs, using bottom-nets and lines with anchors weighing 20-120 kg. Visual inspections of reefs revealed lost longlines and gill nets and other types of fishing gear. Lost nets that were "ghost" fishing covered parts of the coral colonies, but the effects of the nets on the coral colonies themselves was not quantified. Although the fishing techniques clearly break or disturb corals, the researchers assumed the damage was limited compared to the effect of bottom trawling (Fosså no date.).

In the Stone Fence area off eastern Canada, lost longlines were observed loose on the seabed or entangled in corals on 37% of 52 survey transects, while lost gillnets were observed along two transects (Mortensen *et al.* 2006).

In a review on the impacts of bottom fishing gear, Rice (2006) states that decreased habitat complexity results from the physical impacts of fishing gear. This author indicates that the effects of trawling and dredging are well documented, but that the effects of other gear types are less well known. As fishing gear moves over the seafloor, erect features get snagged, boulders are moved and there is a reduction in the roughness of the seafloor. In evaluating the effects of fishing gear on benthic communities, Rice (2006) noted that "areas of higher habitat complexity and lower natural disturbance had higher values of many biotic variables and showed greater differences in benthic faunas between areas opened and closed to fishing."

Unlike in bottom-trawl fisheries, where physical impacts on ecosystems are numerous, sustainability objectives are poorly defined, difficult to agree upon or prioritize, and monitoring is difficult, the impacts of longline and gillnet fisheries are more limited, quantifiable and observable — i.e. bycatch (Jennings and Revill 2007).

According to Chuenpagdee *et al.* (2003) (Table 2, above) bycatch and habitat impacts from pelagic and bottom longlines are "moderate" (ranking with pots and traps), and should require mitigative measures.

ECOSYSTEM/BIODIVERSITY IMPACTS

FAO (2008b) reports that "most ecosystems are diverse, and likely contain one or more species that are highly vulnerable to some human activity." In order to measure the impacts of activities on an ecosystem, the health or state of the ecosystem needs to be evaluated before the activity has begun. In the marine environment, this is often not possible due to a lack of knowledge, understanding and research which can often be costly and difficult to address. Very little is really known about the world oceans, and what biological knowledge there is often comes from fisheries managed for single-species. Hughes *et al.* (2005) point out that currently, the health of an ecosystem is measured by "monitoring abundances of a few conspicuous species." These authors go on to say that "the weakness of this approach is that the mechanisms driving temporal or spatial variation in abundance are often poorly known, and the consequences of changes in these few species to the ecosystem as a whole are rarely considered." Often the only measure we have of aquatic species and their ecosystems is from catch and bycatch statistics of the commercial fishing industry.

Bycatch

Bycatch and discarding of unwanted catch is described as "the most pressing issue facing the commercial fishing industry worldwide", second only to the sustainability of the stocks of the target species (Hall and Mainprize 2005). Bycatch occurs as a result of fishing gear with "imperfect selection properties" (Cook 2003). This leads to millions of tons of unwanted fish and other biomass killed every year. This bycatch is either thrown back to sea, where likelihood of survival can be low (Hall *et al.* 2000) or, if of adequate commercial value, kept and landed. This affects biodiversity by removing top predator and prey species other than the target species (Gilman *et al.* 2008), and becomes a conservation problem when the catch levels are unsustainable or when endangered or threatened species are affected (Hall *et al.* 2000).

Bycatch levels vary among fisheries in quantity and species caught (Revill 2003). Cook (2003) states that over half of the world's discards are from fisheries in the Northwest Pacific (including crab, shrimp, mackerel, jack mackerel, cod and pollock fisheries), the Northeast Atlantic round-fish and flatfish fishery, and the West Central Pacific shrimp fisheries. Kelleher (2005) also states that trawl fisheries for shrimp and demersal finfish are responsible for over 50% of global discards, yet only represent 22% of global landings.

The notorious high seas "driftnet" gillnet fisheries of the 1970s and 80s targeting squid, tunas and billfishes consisted of nets of up to 50 km in length (described by Northridge, 1991), with "a destructive effect on the biomass of targeted species; substantial bycatch of seabirds and marine mammals; a high "dropout" rate of fish that are caught and die but slip free before being harvested; and the risk of "ghost" fishing from unrecovered nets that fill with fish and mammals, sink from the weight, then resurface to repeat the process" (DFO 2006). These nets are distinguished from other floating gillnets primarily by their size, though some of the current smaller scale gillnets in the Gulf of St. Lawrence are also locally called "driftnets". Substantial bycatch in the large scale driftnets, depending on the region and gear-type, included seabirds, mammals, turtles, sharks, and other fish species (including commercially important ones and relatively unknown pelagic species). An international UN convention effectively closed the driftnet fisheries in international waters in 1992. Subsequent actions also closed driftnet fishing by EU countries in the

Mediterranean, though non-EU countries, such as Morocco, continued the practice (Tudela and Guglielmi 2003) despite becoming illegal in 2007 (WWF 2009). Driftnetting in the Baltic Sea was made illegal in 2008. Coastal zone driftnet fisheries with shorter nets are still pursued legally in some countries. For example, Western African countries, particularly Ghana, have an artisanal driftnet fishery for sharks and other large pelagic fish (manta ray, tunas, swordfish, sailfish) that is expanding off-shore to compensate for reduced hake fisheries, Sri Lanka and India pursue a driftnet fishery for sharks and tuna, and a small-scale driftnet fishery continues in Southeast Asia (Morgan and Staples 2006). In the EU Fleet Register, 1289 drift-netting vessels are currently registered as active, driftnetters of different vessel size were still active in 2007. No recent bycatch or impact information on these was found. Illegal driftnet fishing continues in many areas (eg. DFO 2006) though precise data is not available. Canada experimented with a coastal driftnet squid fishery from 1979 – 1987, but terminated this endeavour because of unacceptably high levels of bycatch (McKinnell & Seci 1998).

Gear Selectivity

In the 1950s, when the concept of "selective fishing" was introduced, it referred to selection for a desired size of target fish in the context of a single species fishery (Hall *et al.* 2000). This was a strategy to protect juvenile fish in overexploited stocks (Revill 2003). Gear was thus modified and designed to be size selective, but not to select for a specific species of fish. Today, the idea of "selective fishing" refers to selecting for particular sizes of a target species as well as avoiding the catch of other species, including commercially unviable species or forbidden species (Hall *et al.* 2000).

A CEFAS report (Revill 2003) states that mobile fishing gears, the most commonly used in the world, are generally the least selective of fishing gears (though this may be arguable). Passive gear such as gillnets, can be very size-specific, determined by the mesh size, and therefore considered by FAO to be highly selective (Hovgård and Lassen 2000). However, gillnets do not generally discriminate species caught in the nets, so this factor needs to be controlled by where and how the gear is utilized and/or how to release bycatch in a survivable state (see mitigation measures section below). Longlines can likewise be quite selective depending on how they are used, including size selection of catch through the selection of hooks, but otherwise are not inherently species selective.

Community and Population Structure

Bycatch not only removes unwanted fish and other biomass from the ocean ecosystems unnecessarily, but also has significant collateral impacts on the target species and other species and components of the ecosystem (Cook 2003). For example:

- Within a target species, overexploitation of undersized or immature individuals through bycatch can have serious implications for the sustainability of stocks. The overall body-size of individuals in a fished population may also change with intense fishing pressure on certain sizes (UNGA, 2006).

- When bycatch species are ecologically associated with the target species, such as in predator – prey relationship, the removal of one species and not the other is likely to cause a shift in community structure (Hall *et al*. 2000).

- Bycatch discards, fish offal and dead benthic organisms dumped into the ocean by fishing operations also alters community structure by increasing local concentrations of scavengers and predators (UNGA 2006).

Community shifts of this kind have been evidenced for coral reefs and kelp forests (Hughes *et al.* 2005), and by an increase in the grey seal population *(Halichoerus grypus)* off eastern Canada as a result of a decrease in shark predation - sharks started being caught as bycatch in longline fisheries for swordfish that replaced the earlier harpoon fishery (Brodie and Beck 1983). In the case of the increased seal populations, higher infestations of codworm *(Phocanema decipiens)* in commercially important fish species were also a consequence.

Species behaviour in a community can also be altered. Gilman (2008) states that "bycatch alters foraging habits of species that learn to take advantage of discards". In longline fisheries, this is an important concern for migratory but foraging seabirds, sharks and turtles.

<u>Ghost Fishing</u>

Ghost fishing is a term that describes the effects of lost or discarded fishing on the environment. Smolowitz (1978) and Brown and Price (2005) define ghost fishing as the fishing that takes place "after all control of fishing gear is lost by a fisherman." This phenomenon is most often associated with lost passive fishing gear such as gillnets and longlines, rather than active gear like trawl nets and dredges. The lost gear continues to catch fishes, crustaceans, birds, marine mammals and turtles of both commercial and non-commercial value, possibly indefinitely – depending on the resistance of the component materials to degradation. Ghost fishing is considered the second-most significant impact of gillnets and longlines after incidental bycatch (Revill 2003).

Brown and Price (2005) outline the impacts of ghost fishing on the environment as including continued capture of target and non-target fish and shellfish; entanglement of sea turtles, marine mammals and sea birds, ingestion of gear-related litter by marine fauna, and physical impact of gears on the benthic environment. This author also lists the most common reasons for lost gear, including conflict with other sectors, principally with operators of active fishing gear, working in water depths, weather conditions, or bottom types that are not practically possible for the gear or vessel, and working gear that is too large or numerous to be regularly or adequately tended. A later section describes the effect of lax European Union regulations on the substantial discarding of gillnets.

In recent decades, concern about ghost fishing has increased because most modern fishing gear is made from synthetic, non-biodegradable materials, therefore their impact can potentially last for long periods of time (Brown and Price 2005).

In the Japanese bottom gillnet fishery in the Emperor Seamount and North Hawaiian Ridge areas cited above, the ropes connecting the gillnets to floats on the surface can be cut by other fishing activities and the nets lost. In five years, at least 3km of nets have been lost in the area (Fisheries Agency of Japan, 2008). How long the lost nets continue to catch fish has not been studied.

Anecdotal evidence reported by Hareide *et al.* (2005), observing "Shelf Edge and Deepwater Fixed Net Fisheries to the West and North of Great Britain, Ireland, around Rockall and Hatton Bank" suggests that up to 30kms of gear may be "routinely discarded per vessel per trip." Norwegian investigations in the deep slope gillnet fishery for Greenland halibut (*Reinhardtius hippoglossus*) have shown that "the nets can fish for at least 2-3 years." (Hareide *et al.* 2005, citing Furevik and Fosseidengen 2000). Gillnets lost in deeper water (>400m) can fish for years afterwards because bio-fouling and water movement are very low at those depths. In the Norwegian gillnet fishery for Greenland halibut at depths between 550 and 700m, between 0.14% and 0.17 % of the number of nets used in the season are lost.

Based on those results, Hareide *et al.* (2005) calculated that about 15 nets (750 m) per day are lost in the deep slope fisheries of their DEEPNET report study area.

Summaries of retrieval exercises are limited at present to the grey literature (Large *et al.* 2009). Describing exercises in deep-water gillnet fisheries west of the British Isles and in the Norwegian Greenland halibut gillnet fishery, these authors recommend an underwater camera be used to improve the efficiency of the Norwegian retrieval gear. In Canada, earlier government policies to subsidize the loss of fishing gears, was reversed over a decade ago. This earlier policy fostered the loss of gear. Now, fishers need to justify the loss of gear, which is individually tagged, and replace it themselves. This, together with greater awareness of ghost-fishing impacts and improved GPS technology, has led to reduced loss rates and high recovery rates by the fishers themselves. Nevertheless, sonic tagging of gear is being recommended to further facilitate the recovery of lost gear.

<u>Iconic Species impacts</u>

Research into the effects of commercial fishing on other species most often reports that the species most affected by gillnets and long-lines include marine mammals, seabirds, and turtles. These species are attracted to long-line fishing gear because of the bait. As the gear is deployed, foraging seabirds feed on the baited hooks at the surface and, if hooked, get pulled underwater and drown (DFO 2007a). Sea turtles feed on the bait while the gear is soaking, and, if hooked, also can drown. Birds and turtles, as well as marine mammals, get tangled in gill nets and drown. Sharks are caught as bycatch in both types of gear, and generally killed (sometimes after finning).

Cook (2003) points out that these species do not represent a group that is particularly numerous in bycatch relatively to other species, but attract more public attention and concern. In some cases, mortality from fishing may be particularly significant to the potential survival of an iconic species. Research on bycatch impacts and mitigation strategies have therefore focused on these groups of animals more heavily than on other fish species or invertebrates.

<u>Marine Mammals</u>

Cetaceans in general face probably the greatest recognized threat worldwide from mortality in bycatch (Read *et al.* 2006). Cetacean experts agree that death from entanglement in fishing gear is the biggest threat to global cetacean populations (Revill 2003). It is estimated that on a global scale, 65,000 – 85,000 cetaceans become entangled in fishing gear every year (Revill 2003). Some marine mammals become trapped and drown, while others are able to escape entanglement but break free with remnant pieces of fishing gear stuck to them. These remnants can create drag and become snagged on other objects in the environment, affecting subsequent health or survival of the animals. (Revill 2003)

The North Atlantic right whale (*Eubalaena glacialis*) is considered one of the most critically endangered populations of large whales in the world, with an estimated 300 individuals surviving in the western North Atlantic (Knowlton and Kraus 2001). As such, ship strikes and entanglement in fishing gear (predominantly from the lobster pot fishery, but also in gillnets) may be significant at the population level (Clapham *et al.* 1999). Waring *et al.* (2002), as part of the 2002 U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments, report that while whales may not be killed immediately by entanglement, they may be weakened or suffer subsequent infections from "chronic stressors", as was considered the case with a two-year old whale found dead with a gillnet wrapped about its tail (Kenney and Kraus, 1993, cited in Waring *et al.* 2002) Young whales between 0-4 years appear to most affected by entanglements and ship strikes (Kraus 1990). As noted by Knowlton and Kraus (2001), the whales caught in nets may also drown and sink, possibly leading to an underestimation of mortality.

Studying fatalities of Northern right whales due to human activities, Knowlton and Kraus (2001) developed criteria for defining serious injuries and mortalities from entanglement or ship strikes. They also suggest management could include efforts at disentanglement, modifications of gear and seasonal closures for fisheries.

The Vaquita porpoise (*Phocoena sinus*) is the smallest porpoise in the world, with a current population estimate of only about 500 animals. It is listed by the IUCN as critically endangered, and the WWF predicts that this species will become extinct if current rates of entanglement and drowning in gillnets, about 40 per year, continue (Revill 2003).

Bycatch of whales has been observed by the United States National Marine Fisheries Service (NMFS) "Sea Samplers" program in the pelagic drift gillnet fishery off the Grand Banks and south of Cape Hatteras, but no mortalities or serious injuries were documented in the pelagic longline, pelagic pair trawl, or other fisheries monitored by NMFS (Waring *et al.* 2002.) The only bycatch of a right whale documented by NMFS Sea Samplers was a female released from a pelagic drift gillnet in 1993.

In an anonymous report on *False Killer Whales* for *Hawaii's Wildlife Conservation Strategy 10/6/2005,* fisheries bycatch is stated to be "a major threat" to this species (*Pseudorca crassidens*). This whale is found throughout the Hawaiian Islands in both shallow and deep water, though abundance is stated to be low (a total population estimate of 268 for the Hawaiian Exclusive Economic Zone). Interactions with longline and bottom trawl fisheries can result in death or injuries to dorsal fins that may affect reproduction and survival (Baird and Gorgone 2005). Commercial fishers, who lose yellowfin tuna and mahi mahi hooked on trolling lines to depradation by false killer whales, are also known to deliberately kill the whales.

Seabirds

Longline fishing is considered to be the greatest threat to the survival of some seabird species, drowning thousands of individuals each year of, for example, albatross species that are critically endangered (UNGA 2006; Revill 2003). Evidence suggests that declines of many seabird populations is due to incidental death by capture in gillnet and longline fishing gear (Gilman 2004; DFO 2007a; Revill 2003).

Gilman (2004) reports that the species of seabird most commonly caught in longline gear, by region, are:

- albatrosses and petrels in the Southern Ocean,
- Arctic fulmar (*Fulmarus glacialus*) in the North Atlantic, and
- albatrosses, gulls, and fulmars in North Pacific fisheries.

The Norwegian fishing fleet catches approximately 20,000 northern fulmars every year in longline gear (Revill 2003). However, albatrosses and petrels are the species most at risk. The IUCN reports that 26 of the 61 species of seabirds affected by longline fisheries are threatened with extinction, and 17 of these listed species are albatrosses (Gilman 2004). Albatrosses and other seabirds that get caught on longline gear get hooked when they go after the bait on hooks during setting and retrieval of gear (DFO 2007a).

Gillnets are also responsible for the capture of thousands of seabirds. In Northern Puget Sound, 3500 seabirds were recorded entangled in salmon gillnets in 1994 alone. Rhinoceros auklets and Common murres are the species most frequently caught (Revill 2003; Smith and Morgan 2005). Large numbers of Marbled murrelets are also killed in gillnet fisheries In British Columbia and Alaska (Carter et al., 1995). Penguins in South America and New Zealand have also been reported to be significantly affected by gillnet entanglement (Revill 2003). These diving seabirds get caught in gillnets when swimming under water and drown (Carter *et al.* 1995).

Ghost fishing by lost or abandoned gear is also a significant source of seabird mortality. Between 1976 and 1985, in the North Sea, 13% of the dead gannet washed ashore were entanglement in net fragments (Revill 2003).

Turtles

Loggerhead *(Caretta caretta)* and leatherback (*Dermochelys* coriacea) sea turtles are the primary species caught in pelagic longline gear, though Olive ridley (*Lepidochelys olivacea*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricate*) and Kemp's ridley (*Lepidochelys kempii*) are also captured (Gilman *et at*. 2006a). All species of sea turtles are considered endangered, and their populations have declined so drastically that some groups have called for a ban on pelagic longlining (Gilman *et al.* 2006a). As a result, several longline fisheries have been closed for periods of time, including the Hawaiian swordfish fishery (closed for four years), an area of the North Atlantic within US jurisdiction (partially closed to longlining in 2000 and completely closed in 2001). (Gilman *et al.* 2006). These fisheries have since re-opened, but now have strict management measures in effect to minimize turtle bycatch. These measures include large circle hooks and fish bait rather than squid[4], restricted annual effort, annual limits on turtle captures, 100% onboard observer coverage, and turtle bycatch avoidance methods (Gilman *et al.* 2006) (see also mitigation section below).

Kaplan (2005) reports that bycatch in longline fisheries and coastal sources of mortality are the two likely causes of the decline in leatherback turtle populations in the eastern and western Pacific Ocean. Longline bycatch of turtles accounts for 12% of total annual estimated mortality in the western and central Pacific and 5% in the eastern Pacific. Coastal sources of annual mortality, in comparison, are 13% and 28%, respectively. The author emphasises that efforts to protect leatherback turtles needs to include not only control of bycatch in pelagic longlines, but also control of coastal harvest of adult females and eggs and reduction of bycatch in inshore fishing gear, including gillnet (Kaplan 2005).

Sharks

Sharks also forage on the baited hooks of longline fishing gear (DFO 2007b). It is unknown how many sharks are discarded in longline fisheries in total, but at least ten species of sharks are affected (UNGA 2006). It is estimated that 50% of the global catch of sharks, skates and rays is taken as bycatch (Stevens *et al.* 2000). Blue sharks (*Prionace glauca*) are the most commonly discarded species in longline fishing gear (Kelleher 2005).

Hareide *et al*. (1995), in an investigation of the bottom gillnet fisheries on the continental slopes of the West of the British Isles, found that within a 10 year period the stocks of deepwater sharks were reduced by approximately 80%. This coincides with a significant increase in the gillnet fishery in the area.

[4] A change that is thought to have increased shark bycatch (Gilman 2008)

The issue of shark bycatch is interesting because of the economic benefits it may provide, particularly in developing countries. The market for shark fins is very lucrative so fishers, especially in developing countries, often find the economic benefit of shark bycatch is greater than the costs of a shark interaction (Gilman *et al.* 2008), or may target sharks specifically. Few fishers retain the bodies of sharks because of the low value of shark meat, so the carcasses are discarded. This is illegal in some countries, including Hawaii and Australia. Kelleher (2005) reported that on a global scale over 200,000 tonnes of shark are discarded annually as a result of this "finning" practice. Sharks are, in general, very long lived, of limited fecundity, and, in the case of pelagic species, of considerable individual ranges. This makes the design of a sustainable shark fishery very difficult and the ecological consequences of shark bycatch of great concern to the sustainability of shark populations.

Other fish and Invertebrates

Other iconic species that gain notoriety as bycatch include a variety of species that may have a more restricted geographical range, have conservation "endangered" status, and/or are local cultural icons. The incidental capture of invertebrates is usually a result of demersal trawl fisheries (Revill 2003), but corals and sponges are animals that also are affected by demersal longlines and gill nets. Within Canada, sturgeon, salmon, and steelhead are also of concern as bycatch in gillnets.

VULNERABLE MARINE ECOSYSTEMS (VMEs)

As previously mentioned, vulnerability of an ecosystem is determined by the likelihood of alteration from a disturbance and the likelihood of recovery from this disturbance within a reasonable time frame (FAO, 2008a). These factors depend on, or are related to, both biological and physical structural aspects of the ecosystem. Therefore, vulnerable marine ecosystems (VMEs) may be "physically or functionally fragile" (FAO 2008a). Vulnerability of ecosystems and their component parts need to be determined relative to specific threats, because as FAO (2008a) reports, "some features, particularly those that are physically fragile or inherently rare, may be vulnerable to most forms of disturbance, but the vulnerability of some populations, communities and habitats may vary greatly depending on the type of fishing gear used or the kind of disturbance experienced." Ecosystems that are easily disturbed and slow to recover, or which may never recover are considered the most vulnerable ecosystems (FAO 2008a).

FAO (2008a) reports that "risks to a marine ecosystem are determined by its vulnerability, the probability of a threat occurring and the mitigation means applied to the threat." One of the biggest risks to VME is fishing. The technological advances in the fishing industry have led to a rapid expansion into deeper waters on top of, or around, deep-sea fish habitats that are considered VME. With fishing vessels operating at depths greater than 400 metres, and sometimes up to 2000 metres, VME such as seamounts, cold-water reefs, and ridges and trenches are at risk of over-exploitation that could lead to rapid collapses of fish stocks that may never recover (UNGA 2006), particularly as the species in these environments may be very long lived and with very low functional recruitment rates. For shallower-water biodiversity that could be affected by fisheries, UNGA (2006) notes "when unfished coral-dominated sites sites were compared with heavily fished sites, it was found that biomass at the coral-dominated sites had a seven-fold higher mean sample biomass".

One of the problems with fishing over VME in the deep ocean is that our knowledge of these ecosystems and the complex ecological processes they possess is limited or non-existent, as is our ability to study them. The UNGA (2006) advises "a very precautionary approach to exploiting these areas," as the known effects of fishing in VME are so far very short term and of limited completeness. The UNGA (2006) points out that there is a lack of baseline data, reference points, real-scale experimentation and long-term time series analyses.

Seamount and deep water reefs are the VME that are most likely to be impacted by fishing (UNGA 2006), and these have been the most studied. Even less is known of potential fishing impacts on other VME like cold water seeps, pock marks, hydrothermal vents, sponge fields, oceanic slopes, polymetallic nodules and trenches and canyons (UNGA 2006).

<u>Seamounts</u>

Seamounts are steep-sided undersea mountains that do not break through the surface of the water and have an elevation of greater than 1000 metres from the seafloor. They are of volcanic origin and occur throughout the world's oceans (Morato and Pauly, 2004; FAO online Fisheries Glossary; Smith, no date; Rogers 2004). Smith (no date) explains that seamounts "often occur in clusters along ridges leading to island groups or chains that are physically isolated from other island chains." This isolation results in high levels of endemic species with very limited distribution, and assemblages of species found on and around individual seamounts may not occur anywhere else in the deep-sea (Morato and Pauly 2004; Rogers 2004). Certain extremely long-lived and slow-growing species, as well as examples of 'living fossils,' have been found at some seamounts (Morato and Pauly 2004). Rogers (2004) notes that seamounts are also "important feeding grounds and sites for reproduction for many open ocean and deep-sea species of fish, sharks, sea turtles, marine mammals and seabirds."

Current threats to seamounts are primarily related to fishing. Seamounts are profitable fishing areas for commercial fisheries because dense schools of fish aggregate around seamounts (Morato and Pauly, 2004). Examples of targeted seamount-associated fish include the Orange roughy (*Hoplostethus atlanticus*), Alfosinos (*Beryx splendens* and *B. decadactylus*), Patagonian toothfish (*Dissostichus eleginoides*), Oreos (e.g. *Allocyttus niger*, *Pseudocyttus maculatus*), Pelagic armorhead (*Pseudopentaceros wheeleri*), and several species of Rockfishes (*Sebastes* spp.) (Morato and Pauly 2004). These authors analysed over 14,000 fish species and determined that seamount-aggregating fishes "have higher intrinsic vulnerability than other groups of fishes." This is due to life history characteristics including longer lifespan, later sexual maturity, slower growth and lower natural mortality of these species. This raises important conservation concerns for the species being commercially fished over seamounts and should be reason for a very precautionary approach to managing seamount fish resources (Morato and Pauly, 2004).

The biodiversity on and around seamounts is high. Froese and Sampang (cited in Morato and Pauly 2004) analyzed surveys from 60 seamounts and found 535 species. This represents only 2% of fish species on Earth; however, seamount fishes belong to 25% of 515 families and 47% of 62 orders of fishes indicating that their genetic diversity is very high and that they represent "a relatively large and unique portion of fish biodiversity".

Fishing over seamounts does not only impact vulnerable target fish species, but also impacts non-target bycatch species such as corals, crustaceans and other structured benthic communities (Rogers 2004).

As reported in the earlier cited Japanese study of the Armorhead and Alfonsin gillnet fisheries in the Emperor Seamount and North Hawaiian Ridge areas (Fisheries Agency of Japan 2008), seamounts can often be described as "unique". Despite this statement, no unique species has been found at any specific seamount of those areas. While aggregations of corals exist, the authors indicated that it cannot be concluded that these represent VME, since no quantitative criteria for what constitutes a VME have been established in the FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas. However, it is admitted by the scientists that VMEs may have been present when bottom gillnet fishing began some forty years previously, and the aggregations of corals still in existence may survive only in natural refugia that bottom gillnets do not reach.

Deep Water Reefs

Deep water reefs usually consist of several species of hydroid corals, though *Lophelia pertusa* is the main recorded reef building species of deep cold-water reefs (ICES 2004). *Lophelia pertusa* is a "colonial bank-forming scleratinian coral" that can reach sizes of several hundred metres in diameter and 25 metres in height (Husebo *et al.* 2002). Found in the North Atlantic, the Mediterranean, the Indian and the Pacific Oceans, these reefs are rich in biodiversity. Almost 800 invertebrate and fish species have been recorded on reefs in the Northeast Atlantic Ocean (Husebo *et al.* 2002). Similarly to seamounts, reefs provide important three dimensional structure on a deep-sea bottom that is predominantly flat and muddy, providing habitat to a wide variety of species –both endemic and migratory. However, corals are more fragile than rock reefs, and are of biological origin. Like many other deep water species, these are slow growing, and thus are particularly slow to recover from impacts (ICES, 2004). For example, seven years after a single trawl through a coral reef in the Gulf of Alaska, 7 of 31 colonies were missing 80-99% of their branches (ICES 2004).

Deep water biogenic reefs are subject to long-term physical and ecological damage from fishing throughout the world. In Norway, for example, 30-50% of *Lophelia* reefs have been impacted or destroyed by trawling (ICES 2004). Off eastern Canada, in the Stone Fence area, 90% of *L .pertusa* was discovered dead, presumably due to trawl fishing (ICES 2004). The effects of gillnet and longline fisheries on deep water reefs are not as severe, though longline gear has been observed to break off coral branches, dislodge whole colonies and crush colonies with anchors. Lost longlines and gillnets have been found loose or entangled in the corals (ICES 2004).

Sponge Fields

Sponge fields are found in benthic habitats all over the world, occurring in water as deep as 6,000 metres (UNGA 2006). Researchers believe they are important feeding habitat for various fish species, with reports that sponge fields are "twice as rich in species as the surrounding gravel or soft bottom" (UNGA 2006). Recently discovered glass sponge reefs on the coast of British Columbia are believed to be unique extant examples of a phenomenon that was once widespread in the world's oceans. The significance, biodiversity and distribution of these reefs, with estimated ages in some cases of over 10,000 years, are only now being studied. All sponge reefs are very sensitive to bottom trawling and secondarily sensitive to other benthic impacts of gear described above, though these have not been quantified. In the case of the BC coast, the commercial trawl fleet was asked to avoid the sponge reefs voluntarily in 2000, followed by legislated protection in 2002 that was expanded in 2006 (Living Oceans Society, n.d).

Oceanic Slopes

The continental or oceanic slope begins where the continental shelf starts to drop off. One example of a continental slope is off the Gulf of the Farallones, in California, that begins at a depth of about 200 metres and reaches a depth of 3,200 metres where it meets the deep-sea. The waters at this depth are close to freezing and the water pressure along the continental slope ranges from 10 to 100 times greater than the pressure at the surface. This unique environment consists of species with different life histories and special adaptations to these conditions such as slow metabolisms, higher ages than similar species in shallower waters (e.g. deep-sea rock-fish species can live for more than 70 years), and higher water content in their tissues, bones and shells to deal with the high water pressure. The community structure of continental slopes is stratified with species possessing different adaptations. It is uncommon to find species that occur at all depths along the slope. Usually a species is replaced by another species at different depths. Laigid (2006) explains, for example, that there are 5 common species of skates in the shallow waters of the slope but 3 different species that live deeper along the slope.

Very little is known about continental/oceanic slopes and the communities they support. They remain virtually untouched by humans except for the few commercial fisheries that are beginning to take advantage of these waters. On the continental slope off of California's coast there is a productive fishery for species like Dover sole, sablefish, deep-living rockfishes, thornyheads, rattails, spot prawn and hagfish. Overharvesting these species and communities is a very serious concern, because so little is known about these ecosystems (Laigid 2006).

Polymetallic Nodules

Found at depths from 4,000 and 6,000 metres, polymetallic nodules form flat horizontal fields. Examples include the Pacific central abyssal basin, Central Indian Basin, Crozet Basin among others. These fields support a diverse array of epifauna that provides habitat for other species (UNGA 2006). No data is available on fishing impacts on this ecosystem. The principal interest in this region is for mining which could have considerably greater effects than fishing.

Carbonate Mounds

Carbonate mounds are little-studied steep-sided mounds that are up to 350 metres high, found offshore at depths of between 500 and 1,100 metres. They consist of an aggregate of carbonate sand, mud and silt. Cold-water reef-building corals and echiuran worms are characteristic species associated with carbonate mounds (UNGA 2006). No data is available on fishing impacts or interests on these features.

Hydrothermal Vents

Deep-sea hydrothermal vents occur along ocean ridges where the ocean floor is expanding. Springs of sulphur-laden hot water, originating from geotectonic activities, emanate from the ridges in a variety of isolated locations, including some along the Juan de Fuca ridge on the coast of BC. Unique ecosystems and species based on symbiotic chemo-synthetic bacteria are found at these vents. Relatively little is known about these ecosystems, nor have any effects from fishing been documented.

MITIGATION

Mitigation to ameliorate negative impacts of fishing includes both management strategies and technical innovations. We deal with these in sequence below, though often a good solution is a combination of several elements of each.

The FAO has published various circulars and plans for mitigation of incidental mortality due to gillnets and longlines, starting with the 1999 "*International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries",* which was followed by the national plans of the United States (2001), Australia (2003), Brazil (2004), South Africa (2004), Canada (2007) and Japan (2009). These national plans seek to implement or tailor the FAO's global recommendations to national fisheries areas and species of concern, including those affected by operations of Distant Water Fleets (e.g. Japanese fleets in Antarctic waters). Progress on this process was reviewed in a workshop in September of 2008, with a report still pending. In 2008, Lokkeborg produced a review for FAO also on seabird bycatch, and in 2007, Gilman, Moth-Poulsen, and Bianchi produced a review on sea turtle bycatch, also for the FAO. However, the most recent FAO review of interactions between marine mammals and fisheries was published in 1991.

The ICES (International Council for the Exploration of the Sea) has many hundreds of documents detailing the work of committees and working groups involved in "Theme Sessions" on various aspects of marine science, but we found no specific review on the impacts of gillnets and longlines on aquatic biodiversity or on VME. In one publication that mentions ecosystems (*Ecosystem Effects of Fishing: Impacts, Metrics, and Management Strategies*, 2005), there is no mention of VMEs, only two mentions of gillnets and no mention of longlines.

The NAFO (Northwest Atlantic Fishery Science Organization) likewise has little published work on mitigation, though they have set forth a protocol on dealing with possible VME, under *NAFO Conservation and Enforcement Measures* (2009), (NAFO FC Doc. 09/1 Serial No. N5614), which contains Article 5bis *Encounters with Vulnerable Marine Ecosystems*. The NAFO Fisheries Commission considers its "most important publication" to be the *Conservation and Enforcement Measures (CEM)*" which regulates the fisheries in the international waters of the Northwest Atlantic. In 2007, the NAFO Scientific Council created a *Study Group on the Ecosystem Approach*, which was to meet for the first time in the spring of 2008. A search of the NAFO publication *Journal of Northwest Atlantic Fishery Science* for articles that mention "mitigation" produced zero results; for "gillnet", three results, none to do with impacts; and for "longlines", 15 results, mostly to do with surveys or fishing effort.

PICES (North Pacific Marine Science Organization) also apparently have produced no reviews of environmental effects of gillnets and longlines.

CCAMLR (the Commission for the Conservation of Antarctic Marine Living Resources) has published or supported an abundance of literature on environmental impacts in the Southern Hemisphere, in particular on the mitigation of fisheries impacts on seabird populations. However, the site is not easily searchable and the CCAMLR-funded or relevant reviews that were discovered were discovered through Google searches. One publication easily viewable at the CCAMLR site is "Fish the Sea Not the Sky", a booklet to help fishers avoid bycatch.

ACAP (Agreement on Conservation of Albatrosses and Petrels) is a multilateral agreement begun as an initiative of the Australian government. It came into force in 2004 and now has 13 parties (Argentina, Australia, Brazil, Chile, Ecuador, France, New Zealand, Norway, Peru, South Africa, Spain, United Kingdom and Uruguay). It publishes ACAP Species Assessments, ACAP Conservation Guidelines, Management Plans, Publications on ACAP species and "EDUCATION" materials "for interested persons, students, scholars, and children on the Agreement and on aspects of the biology and conservation of albatrosses and petrels". Under Publications on ACAP species it has "Books, monographs and meeting reports on longline fishing and fisheries, bycatch and mitigation", which contains a bibliography-in-progress.

Project GloBAL (Global Bycatch Assessment of Long-lived Species) is a joint venture between Duke University and the Blue Ocean Institute that has set out to synthesize information on bycatch from various sources and regions in an effort to "assist resource managers to create effective strategies to reduce bycatch of marine mammals, seabirds, and sea turtles."

MANAGEMENT APPROACHES

Ecosystem Approach to Fisheries

The 1973 CITES (Convention on International Trade in Endangered Species) and the IUCN Red List, which began in the 1960s (Helfman 2007), helped to increase environmental awareness and to give rise to stakeholder forums, which then began to place pressure on regulatory authorities to create and enforce management plans geared towards sustainable development and protection of the ecosystem (Jennings and Revill 2007).

An Ecosystem Approach to Fisheries (EAF), a replacement for the term "ecosystem-based management," seeks to address the impacts of fisheries over a whole ecosystem, rather than the narrower impacts on the target species. The 1992 UN Convention on Biological Diversity (CBD 1992) defines the ecosystem approach (EA), as "ecosystem and natural habitats management" to "meet human requirements to use natural resources, whilst maintaining the biological richness and ecological processes necessary to sustain the composition, structure and function of the habitats or ecosystems concerned".

The United Nations - FAO Reykjavik Declaration (Anon, 2001) dealt explicitly with Ecosystem Approaches to Fisheries (EAF) and called on signatories to "introduce immediately management plans with incentives that encourage responsible fisheries and sustainable use of the marine ecosystem". In the next year, the 2002 World Summit on Sustainable Development encouraged application by 2010 of an Ecosystem Approach (EA) to "maintain biodiversity of important and vulnerable marine and coastal areas" and to use the Ecosystem Approach to support the "elimination of destructive fishing practices". National interpretations of international commitments to EA and EAF are widely incorporated into national policy and legislation specific to fisheries, including the revised European Community Council Regulation on the Conservation and Sustainable Exploitation of Fisheries Resources under the Common Fisheries Policy (2002) (Jennings and Revill 2007).

Management systems based on EAF have been adopted by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and in parts of the North Pacific (Jennings and Revill 2007). Changes in gear technology have helped support this process.

SUPPORTIVE TOOLS FOR MANAGEMENT OF IMPACTS

Modeling

Pinkerton *et al.* (2007) state that marine scientists in general do not understand marine ecosystem dynamics well enough to predict how fishing can change the ecosystem, and may never be able to make such predictions. As "complex adaptive systems", ecosystems often "display chaotic behaviour that defies simple analysis and for which it is not possible to develop general predictive models." Nevertheless, models are used to guide fisheries management for bycatch reduction and environmental impacts. Some examples are:

- Williams *et al.* (2008) developed a model to determine bycatch limits for harbour and Dall's porpoises (*Phocoena phocoena* and (*Phocoenoides dalli*) and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) in salmon gillnet fisheries in British Columbia. Limits were based on protective guidelines of the United States' Marine Mammal Protection Act and the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas. The model framework used a minimum abundance estimate (from 2004–2005), maximum rate of population increase, and uncertainty factors to account for imprecise abundance and mortality estimates. The authors suggest that determining the stock structure of small cetaceans in B.C. and refining species-specific entanglement rates in these and other fisheries should be given research priority to improve the performance of this model.

- Bigelow and Maunder (2007) modelled performance of a pelagic longline fishery for big-eye tuna (*Thunnus obesus*) in the central North Pacific. They found that the species composition of the catch was influenced primarily by the relationship between the distribution of hooks and species "vulnerability", which the authors related to depth and environmental variables including temperature, the thermocline gradient and oxygen concentration. Although the study was done to improve tuna catch, rather than to avoid the bycatch of blue shark (*Prionace glauca*), the authors indicate that the model could also be used to lessen bycatch.

<u>Indicators and monitoring</u>

Monitoring the effects of fishing on the ecosystem is essential for wise management. This question, and the most appropriate indicators for monitoring have been the subject of several recent symposia (e.g. Gislason and Sinclair 2000; Kaiser and de Groot 2000; Sinclair and Valdimarsson 2003; Jennings and Kaiser 1998; Daan 2005; and Gislason 1994). According to Gilman *et al.* (2007c), who reviewed efforts of intergovernmental organizations to reduce sea turtle and seabird bycatch in marine capture fisheries, the "standard and scope" of assessing the bycatch of seabirds varies "considerably", with subsequent measures adopted by the States to reduce the bycatch varying "greatly".

As Baird and Gorgone (2005) note, observers on fishing vessels provide the most comprehensive and quantitative data on bycatch but are expensive (Jefferson *et al.* 1994). Examining scars or gear snagged or entangled on animals thrown up on beaches (e.g., Jefferson *et al.*, 1994 and Friedlaender *et al.* 2001) is less reliable, since only a small proportion of dead animals ever wash up on a beach, and scarring from gear may be effaced or obscured by marks left by scavengers. Observations at sea of cetaceans or mammals entangled with gear (e.g., Knowlton and Kraus, 2001) are by their nature random; and questionnaire surveys to fishers (e.g., Baird *et al.* 2002) may not be answered truthfully for fear of management sanctions.

Damage to the dorsal fins of false killer whales (*Pseudorca crassidens*) was observed by Baird and Gorgone (2005) as part of a population study of the whales in offshore Hawaiian waters, where the whales are known to interact with the Hawaii-based tuna and swordfish longline fishery. The authors suggest that the most likely cause of the damage to the dorsal fins, which are known to be important in reproductive thermoregulation, is interactions with longlines.

Mapping

An acoustic imaging system (DRUMS™), devised to obtain high-resolution images of the seabed structure, in order to study the impact of otter-trawling on sandy bottoms, may also be used to quantify impacts of longlines or gillnet fisheries over similar sediments (Schwinghamer *et al.* 1996).

Fader *et al.* (DFO webpage, last modified in 2003), discuss recent research on seabed mapping techniques for habitat mapping, ecological research and fisheries management. Techniques include high-resolution sidescan sonars, multibeam bathymetric mapping systems, precise navigation, precision sampling and photographic systems, as well as advances in digital data processing and scientific visualization techniques.

Bax and Williams (2001), working on the south-eastern Australian continental shelf, explore a hierarchical approach to mapping seabed habitat, taking into account hydrography and geology to aid in interpreting habitat use and vulnerability. Major seabed features were identified, and vulnerability, or resistance to physical modification, was assessed from geological, biological and oceanological properties. The hierarchical approach used combines scientific and fishers' information in order to establish an informed basis for effective spatial management.

Many of these techniques have also been recently integrated and improved substantially by the Canadian Geological Survey, DFO, and NOAA, focussed on the Georgia Strait and Puget Sound (e.g. Galloway 2008).

Spatial management

Some spatial management systems have been developed to support ecosystem approaches to fisheries through reduced gear conflicts or promotion of environmental protection. Witherell *et al.* (2000) report on the development of a precautionary ecosystem-based approach for the management of groundfish fisheries in the North Pacific Ocean off Alaska, where management measures also try to minimize potential impacts of fishing on seafloor habitat and on marine mammals and seabirds.

Under such proposed spatial management plans, management allocates fishing rights in identified marine areas to specific "blocks" (the smallest management area unit), based both on ecosystem characteristics and the need to meet target species objectives. Allocation is based on knowledge of the impacts of different fishing gears on ecosystem "components and attributes" and on knowledge of the components and attributes in the blocks. Fishers are allowed to increase the range of blocks they access if they can demonstrate that their gears and methods aid management objectives. Bottom trawlers, for example, could be permitted to fish a large number of blocks of low-sensitivity habitat or a smaller number of blocks of highly sensitive habitat. It is proposed that such a system would also deal more effectively with gear conflicts than other systems.(Jennings and Revill 2007).

- In Australia, Hobday and Hartmann (2006), studying the quota-managed longline fishery for Southern bluefin tuna, *Thunnus maccoyii* (Castelnau), proposed area restrictions to help minimize bycatch of this tuna by other longline fisheries. A habitat model based on sea temperature was developed to help set area boundaries, after studying temperature preferences of the species with pop-up satellite archival tags on adult tuna.

- Grantham *et al.* (2008) looked into the effects of three different kinds of area closures to limit bycatch of seabirds, turtles and sharks in the South African pelagic longline fishery. Due to considerable variation in bycatch results, temporary spatial closures proved to be better and more economically feasible than either permanent spatial closures or seasonal closures. New Zealand's National Institute of Water & Atmospheric Research Limited (NEWA) is developing an ecological risk assessment for a longline fishery of the Antarctic Toothfish (*Dissostichus mawsoni*) in the Ross Sea, Antarctica, to meet the objectives of Article II of CCAMLR. Prioritised risks fall into four categories: depletion of target species, depletion of bycatch species, ecosystem impacts due to the removal of harvested and bycatch species, and exogenous effects (Pinkerton *et al.* 2007).

<u>Adaptive management</u>

The Japanese bottom gillnet fisheries in the Emperor Seamount and Northern Hawaiian Ridge areas target Splendid Alfonsin (*Beryx splendens*) and North Pacific Armorhead (*Pseudopentaceros wheeleri*). A large-scale driftnet fishery, also for armorhead, (now closed) caught many immature individuals until 1992. While this was one of the factors that may have contributed to the cessation of the driftnet fishery, during this time the bottom fishing was also adjusted to switch to alfonsin during the armorhead spawning season - except during episodic occurrences of strong year classes of armorhead. In the absence of reliable estimations of biomass for the two species in these areas, catch quotas were considered an inadequate basis for management.

Although the Japanese researchers in this case feel that there is no evidence that the bottom gillnet fishery in the seamount area has serious adverse effects on VME, Japan has responded to concerns raised in their Fifth Scientific Working Group and agreed to:

- introduce ("in principle") 100% scientific observer coverage of the bottom gillnet fleet;
- introduce a tentative closed area in the southeastern part of Koko Seamount around the point where *Corallium* spp. was found;
- conduct bottom surveys by drop cameras in 2009 to collect information on potential VMEs;
- "tentatively" prohibit bottom gillnet fishing below 1,500m (called a "new measure" in the report);
- "tentatively" prohibit bottom gillnet fishing in the area north of 45 degrees North;
- tentatively use a voluntary management protocol based on NAFO and NEAFC recommendations to reduce incidental catches of corals, until an international protocol for the Northwest Pacific Ocean is agreed upon (a "new measure"); and
- increase the distance between the sea floor and the bottom gillnet from 70 cm to 100 cm (a "new measure").

New conservative measures for increasing the sustainability of the armorhead and alfonsin fisheries are also expected to benefit bycatch species and protect possible VME. These measures include a cap on the number of fishing vessels, reduced catch quotas, closures during November and December (part of the armorhead spawning season), and a limited increase of quotas even if strong year classes of armorhead occur.

Interactions with loggerhead and leatherback sea turtles and bycatch of seabirds led to a closure of the Hawaii-based swordfish longline fishery from 2000 to 2004, after which it reopened under new regulations (Gilman *et al.* 2007b). Permitted annual interactions with leatherbacks and loggerheads were capped for the fleet. J-shaped hooks were replaced by circle-shaped hooks that tended to hook less turtles and facilitate their safe release. As well, squid bait was replaced by fish bait that attracted fewer turtles. To reduce seabird bycatch, blue-dyed bait was used and the lines set at night. Annual fishing effort was also restricted, and 100% observer coverage was mandated. Capture rates of leatherback and loggerhead turtles fell significantly (by 83% and 90%, respectively), as did the frequency of serious injury to turtles, owing to the improved hook design. Shark bycatch also fell by 36%, while the swordfish catch rose by 16%. However, catches of commercially valuable tuna species fell by 50% and that of mahimahi, opah, and wahoo by 34% (Gilman *et al.* 2007b). Capture patterns of sea turtles in this fishery suggest that turtles cluster together at foraging grounds. Avoiding such temporary turtle hotspots could further reduce turtle interactions (Gilman *et al.* 2007b).

Other examples of adaptive management from California include: the 2001 phasing-out of bottom gillnets for halibut, the preference for harpoon and gillnet fisheries for swordfish (that have demonstrated less bycatch, including swordfish juveniles, as compared to longlines), and the abolition of gillnet fisheries for white seabass in favour of hook-and-line fisheries.

Regulations

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), signed in 1980, came into force in 1982 under the Antarctic Treaty System. In the next years, CCAMLR addressed the incidental mortality of seabirds by longliners, the entanglement of marine mammals in marine debris, and the impact of fishing on the seabed. In 1989, the Commission urged all members of the Convention to minimize the incidental mortality of seabirds (particularly albatrosses) in longline fisheries. In 1991, the CCAMLR adopted the first conservation measure requiring vessels longlining for Patagonian toothfish in the Convention Area to use conservation methods, especially streamer lines to deter birds. Despite CCAMLR's long experience supporting EAF, actual implementation remains a significant challenge in the CCAMLR area.

Hareide *et al.* (2005) reported that lax or variable regulations between countries allowed for substantial unreported bycatch and waste in deep-set gillnet fisheries. Small mesh sizes, excessive soak times, and intentionally abandoned nets are key elements cited by these authors. As an example, for the deep-sea gillnet fishery for anglerfish in European Union, Norwegian and international waters, European Union legislation at the time permitted a mesh size of 220 mm and up to 400 km of deployed nets, whereas Spanish law stipulated a 280 mm minimum mesh size and only 12 km of deployed nets. Spanish-owned vessels were thus registering under flags of countries that followed the EU legislation, leading to substantially greater fishing pressure and mortalities, as well as intentional dumping or abandonment of excess gear.

In response to the Hareide *et al.* (2005) DEEPNET1 report, the Council of European Union Fisheries Ministers agreed in December 2005 to a temporary closure of the deepwater gillnet fishery in the North-East Atlantic, followed in February 2006 by a ban on the use of fixed nets below depths of 200m in these waters, and a similar action by the North East Atlantic Fisheries for the areas in their jurisdiction (DEFRA, 2007). However, Oceana (2007) had suggested that the European Union has "repeatedly ignored international scientific advice" on management for deep-sea sharks, "which make up a significant portion of the bycatch in the anglerfish and hake deep-sea gillnet fishery." The report indicates that the fishery continues to be "riddled with legislative loopholes," for example, by allowing no minimum landing sizes. Anon (1993) suggests that discards can be from between 20% to 80% of the catch in this fishery.

Hall and Mainprize (2005) likewise point out that regulations focussing on retained size limits and quotas may foster increased bycatch and wastage. As alternatives, they point to recent Norwegian and Canadian no-dumping regulations. The difference between the two regulations is that the Norwegian model provides no financial incentive to the fishing vessel to retain bycatch, which the authors favour. In terms of fish population dynamics, research into damaged reproductive capacity and/or increased extinction risk is well linked to policy commitments to sustainable yield, or to preventing a decline in biodiversity (e.g. WSSD 2002). Moore *et al*. (2009), in their review of bycatch monitoring and control policies, point out that gear-specific and species-specific fisheries in the U.S. still develop research, policies and monitoring largely independently of each other. The authors conclude that collaboration between these different fisheries will be needed to achieve the full potential of bycatch reduction initiatives.

Protected areas and closures

Protected areas and fisheries reserves are considered one of the main tools for Ecosystem Approaches to Fisheries management, as it allows for the complete protection of key areas from all direct fisheries impacts, independent of gear type. These areas can provide significant improved sustainability to stocks that rely on key areas for recruitment. However, protection of the best areas from a biological point of view can be problematic from a social point of view, depending on area and country, as there may be intense fisheries or other user interest in the area, and/or low-income communities may depend on the area for survival. Effective protection of far-ranging species can also be problematic. Temporary rotation or seasonal closures, or the more traditional fisheries-specific closures are some partial solutions. For example, the US-based Pacific and Atlantic Ocean swordfish fleets have been subject to large-scale time-area closures, in order to cut back on interactions with endangered sea turtles (NMFS 1999 & 2000). However, as the US fleet comprises less than 5% of the total longline effort in the Pacific Ocean (Lewison *et al.* 2004) and less than 10% in the Atlantic Ocean (Witzel *et al.* 2001), the effect of these fisheries closures on sea turtle bycatch could be limited, depending on the patchiness of turtle concentrations.

Holland and Schnier (2006) propose individual habitat quotas (IHQ) as a link between protected area concepts and fisheries and as an alternative to species-specific bycatch quotas. In this proposal, individual quotas of habitat impact units (HIU) are provided to fishers, from an overall quota set to maintain a target habitat “stock”. The authors feel that this impact measure could be more readily monitored than direct measures of bycatches, as vessel position can be monitored by satellite technology, while bycatch needs to be monitored by observers. They feel that this approach is “considerably more cost-effective than MPA, but that the relative advantage decreases as fish diffusion rates and uncertainty about fish distribution increases.”

Collaboration

Hall and Mainprize (2005) review progress towards achieving reduced bycatch in a variety of fisheries, and conclude that the technical potential is not achieved, primarily for lack of collaboration between regulators and users. These authors feel that, based on research results, the technical capability to achieve a 25-64% reduction in bycatch exists, but without a collaborative approach with the industry to design and implement their use in a practical fashion, this potential will never be achieved.

After examining strategies for reducing seabird bycatch in gillnet fisheries in Puget Sound, Melvin *et al.* (1999) also wrote that "successful bycatch reduction strategies can only be developed in close cooperation with commercial fishers", whose "experience, knowledge of fishing gear, practices, and culture" are "critical to identifying practical strategies" and whose "involvement in the actual research led to establishing credibility of the study within the fleet, and later, acceptance of results." Unfortunately, the authors also note, in an epilogue to their study, that subsequent regulations enacted by the Washington Fish and Wildlife Commission (no sunrise fishing, mandatory use of nets with opaque netting in the upper 20 meshes, and a form of abundance-based management) did not apply to the U.S. treaty tribe gillnet fleet nor to the Canadian gillnet fleet. Together, these take about 90% (Harrison 2001) of the Fraser River sockeye in the ecoregion. "However effective," Melvin *et al.* (1999) conclude, "it appears unlikely that regulations to reduce seabird bycatch will be ecoregion-wide any time soon."

The World Wildlife Fund also points to collaborative processes as a key element to successes in reducing turtle bycatch in longline fisheries (Mug et al. 2008)). Presumably, the threat of closing a fishery, as in the case of the Hawaiian longline fishery, can foster collaboration if the opportunity is provided.

Cox et al., (2007) suggest that the kind of collaborative development and awareness building with the fishing fleet of pinger deployment on gillnets is the key difference between the poor performance of this mitigation measure in the Gulf of Maine and very good performance in a California/Oregon fishery.

International collaboration is also essential for integrated management. For example, North Pacific driftnet fisheries, with unacceptable levels of bycatch, would not have been ended without international collaboration. Japan, while denying that the deep-sea gillnet fisheries on the Emperor Seamount and Northern Hawaiian Ridge area has significant impact on VME (Fisheries Agency of Japan 2008), nevertheless has adopted precautionary management principals that include measures to protect corals, in line with upcoming international conventions. At the same time, the Japanese scientists noted Taiwanese fishing specifically for coral with trawl gear. The scale of the Taiwanese fishery is unknown, and even if Japan were to implement measures to protect VME in the area, the Taiwanese, not being members of the United Nations, are not bound by UN Resolution 61/105. However, international collaboration may, of course, be driven by a variety of other factors.

The DFO in Canada cites collaborative approaches as a key element in developing Integrated Management Plans.

GEAR MODIFICATIONS

Jennings and Revill (2007) suggest that for any fishery, investments in modifying gear and the costs of ensuring acceptance by the fishing industry have to be evaluated against the costs of other management options such as time and area closures or overall reductions in effort. These authors also emphasise that gear design should also be guided by information on the principal impacts of different gears and how these impacts are mitigated by the modifications. They suggest "impact audits" to define the impact, when and where it occurs, and which fleet, sector and gear is responsible. Furthermore, the impacts should be expressed in a common terminology, such as impact-per-unit-time or per-tonne-of-target-species, and must include the specific context (Jennings and Kaiser 1998). Jennings and Revill (2007) also note that some gear modifications may be driven by effects that are difficult to detect at the population or regional scale, but that are politically charged because of the emotive power of a local disturbance that is, “highly visible from shore.”

Jennings and Revill (2007) conclude that the greatest environmental benefits from gear modification will usually be won when gear technologists work with technicians of other disciplines to integrate new gear technology into management efforts where clear incentives or pressures for accepting the new technology exist. Poor acceptance can be accounted for by a natural aversion to the risk of losing marketable catch, the commercial disadvantages of pioneering restrictive techniques that not all fishers embrace, extra work in handling the gear, benefits to other groups that do not benefit the fishers themselves, the cost of the new gear, and gear conflicts. In encouraging the uptake of low-impact gears, direct and indirect costs also have to be studied or predicted before pressing for widespread acceptance, and the feasibility or existence of grants to offset the costs should also be known. Management methods would include real-time monitoring and swift closure of fishing grounds if bycatch target limits are exceeded (Jennings and Revill 2007). Expected changes in access rights may also encourage the adoption of gears that result in more fishing opportunities.

The use of more selective gears usually leads to some loss of the target-sized fish, since precise selectivity is rare (Cook 2003). The need therefore is for gear that increases catch quality (and therefore its market price), reduces fuel and labour costs (e.g. sorting time for the crew), or lessens wear and tear on the gear. Reducing bycatch of undersized target species and of undesired species, such as most benthic invertebrates, can have substantial benefits in the time needed for sorting (Fonteyne and Polet 2002; Revill and Jennings 2005).

Examples from trawl fisheries include (1) the use of turtle-excluder devices (TEDs) in Northern Australian prawn fisheries that resulted in reduced prawn catches of around 6%, but this was compensated for by higher catch quality, since damaged prawns were reduced by 40% (Brewer *et al.* 2006) and (2) the well-received introduction of sieve nets to the shrimp (*Crangon crangon)* fishery in the North Sea, that resulted in catch reductions of up to 10%, but improved catch quality and significantly reduced sorting time on deck (Revill and Holst 2004). A recent example from longline fisheries is the introduction of “umbrella hooks” in Chile that remarkably reduce both whale and bird interactions, reduce labour, and do not influence catches of the target species (Moreno *et al.*, 2007)

Moreno *et al.* (2007) report that the CCAMLR has taken an “ecosystem approach” to fishery management without actually modifying the fishing gear to avoid bycatch of seabirds, preferring management measures such as streamer lines, night setting, line weighting, discharging all offal on the opposite side of the hauling bay of vessels and opening the fishing season only when the birds are absent from the fishing area. Some of these measures clearly are gear modification (if relatively low cost), and the protocols make good use of behavioural idiosyncrasies of bird behaviour, but “ecosystem approach” is probably a misnomer in this case. Nevertheless, this type of integrative and collaborative approach to developing bycatch solutions has resulted in very good options.

Longline gear modifications:

FAO (2008b) divides mitigation measures to reduce bycatch in longline fisheries into four main categories:

(i) Avoid fishing in areas and at times when seabird interactions are most intense (night setting, area and seasonal closures).

(ii) Limit bird access to baited hooks (e.g. underwater setting chute, weighted lines, thawed bait, side-setting).

(iii) Deter birds from taking baited hooks (e.g. streamer (bird-scaring) lines).

(iv) Reduce the attractiveness or visibility of the baited hooks (e.g. retention of or strategic dumping of offal, artificial baits, blue-dyed bait).

Longline hooks can capture seabirds both during the setting of the line from the vessel, when the seabirds attack the bait, and during the hauling in of the line, when the seabirds attack the catch or remaining bait. By far the greatest mortality occurs as the line is set, as hooked birds get dragged underwater to drown (Lokkeborg and Thiele, 2004). Jennings and Revill (2007) summarizes results from reviews by Revill (2003), Valdermarsen and Suuronen (2003) on available mitigative measures to avoid bycatch of different kinds (Appendix 2), Bull (2007) reviewed the effectiveness and relative cost of mitigative measures to avoid bird bycatch on longlines. The most promising approach appeared to be the use of streamer ropes, or "bird scaring lines", to dissuade birds from attacking the baited lines as they sink, used together with weighted bait lines that sink more quickly into the sea. This is now complemented by the use of the Chilean "umbrella system". Likewise, a variety of innovations have addressed mammal and turtle bycatch. These different gear modifications and mitigative fishing practices are described in more detail below:

Bird bycatch

Streamer or bird-scaring lines: Early bird-scaring lines, also called bird lines or tori lines, were generally single ropes stretched from the stern of the boat to hang above the baited longline as it was fed out into the water. The rope itself was hung with fluttering strips of bright plastic meant to scare off scavenging birds until the bait had sunk out of reach. Early problems included the tendency of the plastic streamers to wrap back over the rope with the wind and for the rope to go slack. Birds also still snatched bait at the end of the streamer lines (see Boggs, 2001). The promise of the method, however, was enough that by 1999 the use of bird scaring lines had become mandatory in the fisheries of the member nations of the Commission for the Conservation of Southern Bluefin Tuna (or CCSBT) (FAO, 1999).

More recent work in Alaska by Melvin *et al.* (2001) and others has helped make streamer lines more effective. In a model described by Melvin, streamer lines stretch from a boom pole at the stern of a boat (suspended "at least 20 feet" above the water) to a towed drogue, usually a buoy. Best used in pairs (also see Revill, 2003), the lines are preferably hung with brightly coloured tubing heavy enough to hang vertically from the line in moderate to strong winds and to create a moving "fence" to protect the groundline from birds until it sinks underwater about 50 fathoms from the boat (the "bird zone" for Alaska seabirds, which generally feed within one fathom of the surface; shearwaters, however, dive frequently and can dive down to 35 fathoms (Melvin, 2000)). Paired streamers are preferred over single lines because they work regardless of wind direction. Slowing the vessel while setting the gear also reduces the exposure of the groundline, which thus sinks closer to the boat. Streamer lines of the design illustrated by Melvin are made available to members of the Alaska longline fleet at no cost by the U.S. Fish and Wildlife Service through the Pacific States Marine Fisheries Commission. According to the American Bird Conservancy (ABC, 2001), reporting on Melvin's 2000 study, the paired streamer lines cost around $260 (U.S.) and eliminated albatross and Northern Fulmar (*Fulmarus glacialis*) mortality. Adopting this new technology two years before it was required resulted in an eight-fold decrease in seabird mortality for both sablefish and Pacific cod longliner fleets. Based on this research, Antarctic seabird avoidance requirements were also modified in 2003 (Melvin *et al.*, no date). The skua is one bird species that is not discouraged by streamer lines, continuing to forage close in under the line where it hangs above the back of the vessel (Biodiversity Group Environment Australia and the Threat Abatement Team of Environment Australia, 1998, citing Brothers, 1993).

ACAP (2007) reviewed the effectiveness of single and paired streamer lines, and noted that baited hooks are unlikely to sink beyond the diving depths of diving seabirds in time without other measures such as line weighting, underwater setting or night setting. Outstanding issues include entanglement with fishing gear, which can lead to poor compliance by fishers, greater difficulty in hauling in the longline, and entanglement of paired lines with each other. ACAP mention two studies in progress to develop optimal bird-scaring lines for pelagic fisheries by the Washington Sea Grant and the Japanese Global Guardian Trust.

Bird-scaring lines are currently the only mandatory mitigation measure in Australian waters (Biodiversity Group Environment Australia and the Threat Abatement Team of Environment Australia, 1998) and are mandatory for Canadian Pacific Groundfish fisheries, dependent on vessel size and location (DFO, 2009/2010).

Weighted longlines: In FAO's International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (1999), which lists technical (and operational) measures to reduce the number of encounters between seabirds and bait, the first technical measure listed is to increase the sink rate of baits by weighting the longline. In practice, extra weights can indeed sink longlines more rapidly, giving seabirds less time to snatch at hooks.

Robertson (2001) suggested that bird-scaring lines and weighting the mainline to achieve sink rates of >0.3 m/s should greatly reduce albatross bycatch. He recommends 4 kg weights distributed every 40 m for boats and gear similar to those of the autoline vessel he used. The 40 m spacing between weights appeared to be the best spacing to minimise "bellying up" of the section of line between the weights.

In a subsequent study published in 2007, Robertson *et al.* presented results of an experiment with line weights on a Spanish-rig longline fishing vessel (working in demersal and semi-pelagic fisheries). They examined the effect on sink rates of setting speed, distance between line weights and the weight of the line weights. Overall, setting speed had only a minor effect. The mass of the weights and distance between them principally determined the sink rates. To minimise encounters with seabirds, the authors suggest 8 kg per 30 m, which give the fastest sink rates practical for Spanish system gear "without overly compromising fishing operations." The authors recommend that weighted lines used with streamer lines and slower setting speeds could reduce mortality of albatrosses and deep diving seabird species to very low levels.

However, as Robertson (2001) points out, the total amount of extra weights that would have to be carried for the longlines has implications to the fishers. Fifteen km of line with 10,000 hooks, at 1.5 m between hooks, would add 4.5 metric tons to the weight of the ship. Crew can also be hit by flying hooks when the line is hauled in closer to the boat (Boggs 2001, Revill 2003) and weights increase labour during setting and hauling (Robertson, 2001). For these reasons, Robertson states, "no Spanish system vessel has adopted the CCAMLR-recommended line weighting regime." He concludes: "provided sink rates exceed 0.3 m/s and a properly configured streamer line is used, this should be all that is necessary to reduce, to very low levels, albatross deaths in toothfish longline fisheries."

Lines with leaded cores, or integrated weight (IW) lines, are perhaps more effective and economical than lines with weights attached, and address some of the practical problems listed above. These were tested in 2003 by Robertson *et al.* The sink rates of the lines in still seawater were found to be two to three times faster (45–52 cm/s) than conventional (unweighted) lines made from polyester, and they appear to improve line handling in general for the fishing operation, increasing efficiency by 10-20%. This group indicates that the technique has been adopted throughout the New Zealand ling autoline fishery.

- In the New Zealand ling (*Genypterus blacodes*) autoline fishery, Robertson *et al.* (2006) tested weighted longlines with a 50 g/m beaded lead core under a single streamer line to avoid bycatch of white-chinned petrel (*Procellaria aequinoctialis*) and sooty shearwater (*Puffinus griseus*), "two of the most difficult seabird species to deter from baited hooks". Mortality of the white-chinned petrels fell by 98.7% in 2002 and by 93.5% in 2003, and in 2003 sooty shearwater mortality fell by 60.5%. No albatrosses were caught on either leaded or unleaded line in 2002, and in 2003 a single Salvin's albatross (*Thalassarche salvini*) was caught on the unweighted line. There was no statistically significant difference in the catch of ling.

- Dietrich *et al.* (2008), in "the largest and most comprehensive experiment of its kind" evaluated the mitigation benefits of leaded longlines in Alaskan demersal longline fisheries in the Bering Sea over a five-month period, on two vessels targeting Pacific cod (*Gadus macrocephalus*). The leaded line was tested alone and with paired streamer lines and conventional longlines were also tested with paired streamer lines. The leaded lines sank astern of the vessel in almost half the distance needed for conventional lines. Using them with the paired streamers, bycatch of surface foragers *(Fulmarus glacialis* and *Larus spp.)* was cut completely and the catch of the more persistent deep-diving short-tailed shearwaters (*Puffinus tenuirostris)* fell by 97% relative to the control, which was an unweighted line used without streamers. The authors concluded that the weighted lines deployed with paired streamer lines were "the best management practice for seabird conservation in demersal longline fisheries using autoline." They also found that handling characteristics of the weighted lines were superior to those of unweighted lines.

ACAP (2007), reviewing the literature, observe that weighting is a supplementary measure to other methods, e.g. bird-scaring lines and/or night setting, since the zone behind the vessel where birds can be caught can be "shortened but not eliminated" by weights. Research is recommended into weighting regimes, "safe leads"[5] (currently being tested), the effects of the weights on seabirds as well as target catches, and integrated-weight branch lines (wire trace) in pelagic fisheries. In the current absence of global standards, and based on research in Hawaii and Australia (Brothers, 1991; Boggs, 2001; Sakai *et al.*, 2001; Brothers *et al.*, 2001; Anderson and McArdle, 2002; Gilman *et al.,* 2003b Robertson, 2003; Lokkeborg and Robertson, 2002; Hu *et al.*, 2005), ACAP recommends a "minimum of 45 grams weight attached to all branch lines; less than 60 grams…within 1 meter of the hook; greater than 60 and less than 80 grams…within 2 meters of the hook; greater than 80 grams and less than 100 grams…within 3 meters of the hook; and greater than 100 grams…within 4 meters of the hook, with a view to obtaining a sink rate of 0.3m per second to a 2m depth."

Interestingly, the Moreno *et al.* 2007 report considers the CCAMLR protocol to reduce bird bycatch an "ecosystem approach to fishery management" with minimal gear modifications. These include: streamer lines, night setting, line weighting, discharging all offal on the

[5] From ACAP 2007: "Researchers in New Zealand , Australia, and the US will be testing "safe lead", a new product which promises to eliminate safety issues related to weighted branchlines. It is planned to pilot-level test these weights in 2007 within Australian, New Zealand and US (Hawaii) fisheries."

opposite side of the hauling bay of vessels and opening the fishing season only when the birds are not numerous in the fishing area.

Side-setting: A third treatment tested by Gilman et al. (2007a), called side-setting, entailed throwing baited hooks from the side of the vessel, using a “bird curtain” to prevent birds from getting at the hooks before the hooks sink out of reach. For both tuna and swordfish gear this method was both the most effective and the most commercially appealing. After modifications to the vessel deck (estimated to cost on average less than $1000 (US)) there are no further costs, and deck space is also increased by condensing the gear storage area. The authors concluded that, if line weighting is adequate, side-setting can also reduce seabird mortality in other pelagic as well as demersal longline fleets. However, research on other fisheries and with seabirds other than Blackfooted (Phoebastria nigripes) and Laysan (P. immutabilis) albatrosses still needs to be carried out.

ACAP (2007), in a review of the literature, note that a definition of the side-setting method is essential. They further note that it is effective only if the hooks are sufficiently deep by the time the longline reaches the stem of the vessel and cite a Japanese report (Yokota and Kiyota 2006) that states the method must be used with other measures, e.g. weighted branch lines. In the Southern Hemisphere, ACAP recommends the method be use with bird-scaring lines until further research is carried out in the region. Construction and operational specifications are given for the “bird curtains” in the ACAP report (citing Gilman and Brothers 2006; Yokota and Kiyota 2006).

Night setting: Setting baited lines at night has been recommended as a low-cost mitigative measure for bird bycatch. Sanchez and Belda (2003) consider that the effectiveness of this measure depends on whether the scavenging birds attacking the bait are active at night, and suggest that night setting may also reduce targeted catch. In 1998 and 1999, studying longline bait losses near the Columbretes Islands (NW Mediterranean), they noted that most of the attempts (80%) to take the bait (predominantly by Cory's shearwater Calonectris diomedea) happened around sunrise and sunset. Accordingly, they suggest that Mediterranean longline fisheries set their bait at night or during the day, and not in the morning or early evening, when the birds are most active.

Bull (2007) is one of several authors who mention night setting in longline demersal and pelagic fisheries as part of a combination of measures that could include, for example, line weighting and bird-scaring lines, “particularly in Southern Hemisphere fisheries.” Other proponents include the Biodiversity Group Environment Australia and the Threat Abatement Team of Environment Australia, in their 1998 “Threat Abatement Plan for the Incidental Catch (or bycatch) of Seabirds During Oceanic Longline Fishing Operations”, and FAO (Lokkeborg and Thiele, 2004).

Klaer and Polacheck (1998) analysed seabird bycatch data from Japanese longline vessels (apparently off Tasmania) and found that setting the lines by night decreased the “chance” of hooking seabirds by five times over setting by day, and that for the lines set at night “the chance of catching seabirds during the full half-phase of the moon was five times greater than during the new half-phase.”

ACAP (2007) note that night setting is “less effective during full moon, under intensive deck lighting or in high latitude fisheries in summer.” It is also “less effective on nocturnal foragers e.g. White-chinned Petrels.” (Cherel *et al.*, 1996 and Brothers *et al.*, 1999). They recommend the method be used with bird-scaring lines and/or weighted branch lines. Research needs are identified to be “data on current time of sets by WCPFC fisheries” and “effect of night sets on target catch for different fisheries.” As minimum standards they recommend night be defined as nautical dark to nautical dawn, and that only the lights necessary for safety on the ship be used while night setting (citing Duckworth, 1995; Brothers *et al.*, 1999; Gales *et al.*, 1998; Klaer and Polacheck, 1998; McNamara *et al.*, 1999; Gilman *et al.*, 2005; and Baker and Wise, 2005).

Bait-setting capsule: Smith and Bentley (1997), working with surface longliners in New Zealand to reduce capture of seabirds, discuss a device described as a "weighted capsule with a triggered release mechanism" which is "attached to a single cable for release and retrieval by … a hydraulically-powered winch." The capsule itself is a fibreglass tube 500 mm long and 100 mm in diameter. A weight is attached to the nosecone of the capsule to make it sink to the desired depth. At that depth, the cable is winched back, and that action opens the capsule and releases the bait though the nose cone. After correcting some operational and design deficiencies, the authors make several recommendations, the last of which is to reduce the number of moving parts within the mechanics of the capsule unit.

Setting chutes: Setting chutes are underwater funnels though which longlines can be set, theoretically out of the reach of seabirds. Because the tube is fixed, the exact depth at any moment depends on the degree of pitch of the vessel (Lokkeborg, 2001).

Lokkeborg (2001 and 2003) tested the chutes in the north Atlantic longline fishery along with bird-scaring lines and line shooters and found that, while all methods were effective at reducing bycatch of seabirds, the most effective and feasible was the bird-scaring line.

- In 2003, Gilman, Boggs and Brothers, working in the Hawaii pelagic longline tuna fishery, tested underwater setting chutes and found the chute to be "95% effective at reducing albatross contacts with fishing gear compared to a control" and thus the "most effective technology tested to date to minimize seabird capture in this fishery". The cost of the chutes was calculated to be recoverable after two fishing trips. Still in 2003, Gilman, Brothers and Kobayashi mentioned engineering deficiencies and expressed concern that the problem of tangled gear around the chute on vessels that set their main line slack, such as the Hawaii longline tuna fleet, would prove to be insurmountable. Four years later, in the trials in which they found thawed, blue-dyed bait to be commercially unattractive as a method to reduce seabird bycatch, Gilman, Brothers and Kobayashi (2007a) again tested the chutes. While the method was more effective than thawed baits, it was not as effective as side-setting and "engineering deficiences" continued to render the chute commercially impractical for the pelagic longline industry.

- Working with a demersal longline fishery for Patagonian toothfish (*Dissostichus eleginoides*) off the Prince Edward Islands, Ryan and Watkins (2002) tested a Mustad underwater setting funnel to reduce bycatch of seabirds, mostly locally breeding albatrosses and petrels. When the funnel was used both day and night and with a bird-scaring line, bycatch was "three times lower." Used during the day, the funnel led to lower catch rates than night setting without it. However, since albatrosses continued to be caught in small numbers even with the funnel during day-setting (which otherwise could increase fishing efficiency over night setting), the authors suggest close monitoring and testing a range of alternative mitigative measures to be used with the chute.

Andrew Revill, chief scientist behind a report on environmental impacts of technological innovation for CEFAS (Revill, 2003) gave "setting tubes" a failing mark owing to inconsistent and ineffective mitigation. Melvin *et al.* (2001) also report that the underwater chute method is considerably less effective without streamers. Despite these misgivings, Melvin *et al.* (2001)

report that some fishers are taking up the method and that it has been mandated by some US states.

ACAP (2007), after reviewing the literature (Brothers, 1991; Boggs, 2001; Gilman *et al.*, 2003a; Gilman *et al.*, 2003b; Sakai *et al.*, 2001 & 2004; Lawrence *et al.*, 2006) echoed the conclusion of Revill (2003). The chutes were judged insufficiently sturdy for large vessels in rough seas and to suffer from malfunctions and inconsistent consistent performance (e.g. Gilman *et al.*, 2003a and Australian trials cited in Baker & Wise, 2005)

<u>Marine mammal depradation and bird bycatch mitigation</u>

Net sleeves : Moreno et al. (2007), working with the Chilean artisanal longline fishery for Patagonian toothfish (Dissostichus eleginoides) in fisheries predated by killer whales (Orcinus orca) and sperm whales (Physeter macrocephalus) describes adding a windsock-shaped net sleeve to secondary vertical lines. In this system, the traditional Spanish longline ("trotline") is modified to eliminate the hook line and place the hooks instead in bundles on secondary weighted branch lines that extend from the vertical main line. Above each bundle of hooks is an "umbrella" net sleeve that covers the catch. The method has "practically eliminated depredation of fish" by the whales (from a maximum of 5% in 2002 to 0.36% of the total catch in 2006). Moreno et al. also report that sperm whales disappeared from the fishing grounds after a week of failing to get at the catch.

The system also works to reduce seabird mortality, with the number killed falling from 1,542 in 2002 to zero in 2006. No birds were killed during the setting of almost 4 million hooks during the breeding season of the seabirds in the area, from October–December. The rapid sink rate of the main line and the relatively small area in which it enters the water is the main reason seabird mortality is eliminated (Moreno *et al.*, 2007).

Another advantage of the system is that it requires fewer crew members (8 instead of 12 for the traditional Spanish system) and results in fewer entanglements of the main line. The net sleeves cost around $25-30 (US) each but are quite durable. In 2006, Catch per Unit Effort (CPUE) was also higher than in at least three of the previous four years, indicating no effect on fish catch rates.

A similar "Mammal and Bird Excluding Device" (MBED) has also been used by Russian longliners in the South Atlantic off Uruguay in the same season (Zaytsev, 2007; Pin and Rojas, 2007 & 2008). Depredation became negligible after the protection net had been introduced which indicates that the method is equally successful to the Chilean and Uruguayan development in deterring cetaceans.

These Chilean "umbrella" net sleeves were the highlight of FAO workshop on updates for reducing bird bycatch held in September, 2008 (FAO, 2008b).

Turtle bycatch mitigation:

Circle hooks: Traditional "J" - shaped hooks used in longlining tend to hook turtles very effectively and in fashions that make benign removal of the hook very difficult, particularly if the hooks are swallowed and get snagged on internal organs. Circle hooks have the barb of the hook pointed back at the shank, with no offset – a design that results in less intestinal snagging if the hook is swallowed, and easier removal from the jaw once hooked there. They have been promoted for some time in hook-and-release sport fisheries (Straughn 2003). Versions of the hooks have also been promoted by the World Wildlife Fund and the IATTC to reduce turtle bycatch (Mug et al. 2008). Depending on the size and design of the hook, the circle hooks can reduce both the number of turtles caught and increase the survival of captured turtles, though reduced catch of target species can be a concern (e.g. Kim et al., 2007). A number of studies and reviews have looked at this issue, including:

- Gilman *et al.* (2007c), in an FAO review, reported that the use of circle hooks in the Hawaii-based swordfish longline fishery significantly reduced capture and injury rates of leatherback and loggerhead turtles.

- Watson *et al.* (2005) compared the use of circle hooks of different sizes and offsets with J-hooks, as well as the use of squid or fish baits, within the pelagic longline fisheries for tuna and swordfish in the western North Atlantic Ocean. Compared to the J hooks, the circle hooks decreased loggerhead (*Caretta caretta*) bycatch by 90% when baited with mackerel and by 86% when baited with squid. For leatherbacks (*Dermochelys coriacea*), circle hooks baited with mackerel reduced catch by 65%, and circle hooks baited with squid decreased catch by 57%. The circle hooks also significantly decreased gut-hooking in loggerheads. Most of these leatherbacks were hooked in the flippers or the carapace or entangled in the lines or both. Unlike loggerheads, leatherbacks are unable to manoeuvre backwards (Watson *et al.*, 2005, citing Davenport 1987 and a personal communication from J. Wyneken), and so may have been foul-hooked while trying to reach the bait. Of the eight leatherbacks hooked in the mouth, seven were hooked on circle hooks (six of these with the 10° offset). Of the total of eight hooked in the mouth, seven were taken on squid. The authors conclude that the use of 18/0 circle hooks and mackerel bait in place of squid can significantly reduce loggerhead and leatherback sea turtle bycatch in the Western Atlantic pelagic swordfish longline fishery. Used together, the two treatments can decrease "interactions" by 90% for loggerheads and 65% for leatherbacks, with no negative impact on swordfish catch. Since many different sizes of leatherbacks in that area were foul hooked, the authors propose that their results can apply to leatherback turtles in other geographic areas and that smaller circle hooks will likely be as effective in reducing foul hooking. Regarding loggerheads however, smaller circle hooks (16/0) were not more effective in cutting "interactions" than smaller J hooks (9/0), and effectiveness depends on the loggerhead turtle class sizes, since hooking can be a function of jaw size and mouth opening. The authors therefore urge that their results not be extended to areas where loggerhead turtle size distributions may vary. (See also Bolton and Bjorndal, 2005 for a comparison of circle hook 16/0 non-offset, circle hook 18/0 non-offset, and Japanese tuna hook 3.6 mm in the swordfish longline fishery off the Azores.)

- Read (2007), in a review of experiments with circle hooks, suggests that room for fishery-specific refinements to the use of the circle hooks remains. Reviewing extensive field trials in five areas of the western North Atlantic, the Azores, the Gulf of Mexico, and Ecuador (more than 1.5 million hooks between 2000 and 2004), the author found that in four out of five fisheries the sea turtle capture rates were reduced and hooking location were more benign, with no significant effect on capture of the target species. However, in one example, catch of the target species fell to a level that made the circle hooks impractical, and in another the reduction of turtle bycatch was not great. Before being used in a specific fishery, he suggested, hooks should be tested on how their shape and size interact with the actual size of the turtles and target species within the specific fishery.

- Gilman and Zollett *et al.* (2006) report on an experiment in the US North Atlantic longline swordfish fishery testing 4.9 cm wide circle hooks with fish bait against 4.0 cm wide J hooks with squid bait. Bycatch rates for sea turtles and the proportion of hard-shell turtles that swallowed hooks versus being hooked in the mouth were significantly reduced by the circle hooks, with no losses in target catch rates. Gilman and Zollett *et al.*, however, advise that viability and cost of using these large circle hooks in other fisheries would have to be tested.

- Ward *et al.* (2009) studied the "performance" of circle hooks in commercial pelagic longlines off eastern Australia that used both circle hooks (mostly size 14/0) and Japanese tuna hooks. While there were no significant differences between the hooks regarding where the "animals" were hooked (mostly in the lip or jaw for both hook types) and no difference in the mean size of animals caught, (with the exception of striped marlin (*Tetrapturus audax*) which tended to be larger on tuna hooks), most species had an equal or lower probability of being alive on circle hooks than on tuna hooks. Because circle hook catch rates exceeded those of tuna hooks for most species (including several target species, such as albacore tuna (*Thunnus alalunga*), yellowfin tuna (*T. albacares*) and striped marlin as well as bycatch, including several shark species), the circle hooks promised greater financial returns, which should encourage adoption.

- Yokota *et al.* (2009) pursued the issue of affects on other bycatch, and studied the effects of circle hooks on blue shark *Prionace glauca* catch in a pelagic longline fishery off the coast of Japan. Compared against conventional tuna hooks, two sizes of circle hooks (4.3 sun and 5.2 sun) did not significantly affect catch rate or mortality of blue shark. Bolton and Bjorndal (2005), however, based on their inconsistent shark bycatch results in work with the swordfish longline fishery off the Azores, suggest that possible increases in blue shark capture rates with circle hooks should be studied further.

- Watson et al. (2005) compared the effects of different styles of circle hooks and J hooks on the catch of blue shark. They found that hooking location varied by hook type and that greater circle hook offset and the use of J hooks lead to greater gut hooking after swallowing.

- Carruthers et al. (2009) found that the survival of swordfish, yellowfin tuna, pelagic stingray, porbeagle and blue shark was significantly greater on circle hooks compared to J-hooks in the Canadian Altantic swordfish and tuna longline fisheries. However, no conservation benefit was found for loggerhead turtles (*Caretta caretta*) from circle hook use.

Fishing depth: Experimenting with longlines in the Hawaii-based pelagic tuna fishery, Beverly et al. (2009) set hooks deeper than usual to examine whether bycatch of fish, protected sea turtles and marine mammals could be reduced without affecting the catch of bigeye tuna (Thunnus obesus). While both deep and shallow hooks caught similar numbers of bigeye tuna, the deeper hooks caught significantly more sickle pomfret (Taractichthys steindachneri), a marketable bycatch. However, fewer wahoo (Acanthocybium solandri), dolphinfish (Coryphaena hippurus), blue marlin (Makaira nigricans), striped marlin (Kajikia audax) and shortbill spearfish (Tetrapturus angustirostris) took the deeper hooks. The differences in catch rates at the different depths were presumed to be due to vertical habitat preferences. The main functional drawback to fishing deeper is the time needed to deploy the necessary additional weights, floats, and floatlines (half an hour) and to retrieve the gear (about two hours).

Gilman and Zollett *et al.* (2006), quoting other studies that note that marine turtles are generally found above 40 m depth, suggest that setting longline gear below these depths could decrease bycatch. They also cite other reports (including Arauz, 2000) presenting "clear evidence" that deep-set fisheries have lower marine turtle bycatch than shallow-set fisheries.

Line-shooting: Hand-set lines into still water sink significantly faster than longlines set from a fishing vessel, presumably because of the effect of the sea swell and upwellings from the propeller, which results in "lofting", or the floating of the line on or near the surface (FAO, 2008b).

Line-shooters actively propel the mainline (trotline) away from the boat during setting, thus both reducing the drag and moving the line away from boat-induced turbulence, allowing it to sink faster. In an experiment off the coast of Norway, longlines set with the line shooter were found to sink to a depth of 3m, 15% faster than lines set without the line shooter. Beyond this depth sinking rates were similar, about 15 cm s^{-1} (Lokkeborg and Robertson 2002). When a line-shooter was tested with a bird-scaring line to attempt to reduce mortality of northern fulmars (*Fulmarus glacialis)*, Lokkeborg and Robertson (2002) found that fewer mackerel baits were lost when the bird-scaring line was used, but not when the line shooter was used alone. The different setting methods had no significant effect on fish catch. Melvin *et al.* (2001), testing a Mustad line shooter in demersal longline fisheries in the Gulf of Alaska and the Bering Sea, found it actually increased seabird bycatch, and was therefore not recommended.

ACAP (2007) notes that line shooting has been quantitatively tested only in the demersal fisheries cited by Melvin *et al.* (2001), with apparently negative results, and states that more data is needed before adoption. Nevertheless, lineshooters were mandatory for the use of monofilament longlines in the Hawaiian longline fishery in 2004, though they are now voluntary (http://www.hawaiilongline.org/ index.php?id=regulations).

Bait-casting: Bait casting/throwing machines cast the baited branchline out to the side of the vessel, away from the turbulence of the ship and its wake, making the setting process more efficient and consistent. Floats are tossed just starboard of the midline or at the midline. (For an illustration, see Figure 1 in Melvin and Walker, 2008).

ACAP (2007) does not recommend bait-casters unless they can cast the bait accurately, particularly under a bird-scaring line. At present, the group feels that "few commercially available machines have this capability" (citing Duckworth 1995; Klaer and Polacheck, 1998). Along with night setting and bait thawing, bait casting is currently practised on a voluntary basis in the Australian Fisheries Zone (Biodiversity Group Environment Australia and the Threat Abatement Team of Environment Australia, 1998).

Thawed bait: FAO's International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (1999), in its list of technical measures to reduce the number of encounters between seabirds and bait, had "thawed bait" and "punctured swim bladders" as the top-ranked measures. These were associated with the use of weighted lines, which is the first measure recommended. All increase sinking speed, as puncturing the bladder and thawing both decrease buoyancy of bait. Possible costs, however, include bait thawing racks, bait loss, and bait spoilage (Gilman et al., 2007a).

ACAP (2007) considers bait thawing as a supplementary measure that should be combined with other measures. If the line is to be set in the early morning, "full thawing of all bait may present practical difficulties." The sink rate of partially thawed bait also requires research (citing Brothers 1991; Duckworth 1995; Klaer and Polacheck, 1998; Brothers *et al.* 1999).

Dyed bait: Bait dyed blue with food colouring can help reduce seabird bycatch by making the bait harder to see in the water and, once seen, by making it harder for the seabird to judge the distance of the bait as it sinks into the water. The dyed baits can also be used to reduce turtle bycatch in longline fishing, as suggested by the FAO (2003), using the example of the Hawaii-based swordfish longline fishery where blue-dyed bait is set out at night to avoid seabird bycatch but also catches less turtles. The food-colouring dye is also relatively inexpensive, approximately $1.00 U.S. per 100 squid (Boggs, 2001), and easy to apply, though there is some increased labour requirements. "Bluish-looking" fish are the only allowable bait in Hawaiian longline fisheries. Bait is required to be thawed and "dyed blue to a specified darkness" matching an NMFS - issued color control card (http://www.hawaiilongline.org/ index.php?id=regulations).

- Cocking *et al.* (2008), investigating how well wedge-tailed shearwaters (*Puffinus pacificus*) could distinguish the dyed baits from the surrounding seawater, noted that neither the fish nor squid baits were "perfectly cryptic" and only the blue-dyed squid were "relatively cryptic". Assessing the responses of seabirds in sea trials of both submerged and "surface-presented" baits, the study observed that almost half of the dyed fish baits presented on the surface were struck by seabirds, while only 3–8% of blue-dyed squid baits were hit (in contrast to 75–98% of the non-dyed squid bait). By the third day of trial, however, 90% of the dyed fish baits were being struck – presumably as the dye leached out.

- Testing the practical applicability of several methods for reducing seabird bycatch on a Hawaii-based pelagic longline vessel south of the Northwestern Hawaiian Islands, Gilman *et al.* (2007a) found that thawed, blue-dyed bait was ineffective because of the time needed to dye the bait, the greater loss of thawed bait from hooks and the fall in bait quality during delays in getting it into the water. However, they indicated that commercially available pre-dyed bait might help to offset these drawbacks.

- Noting that superficial longlines are used to catch common dolphinfish offshore of Brazil (i.e., the hooks remain close to the surface at all times) Lokkeborg and Thiele (2004) suggest that the only known mitigation measures against seabirds are streamer lines during setting, night setting and the use of blue-dye baits (still at "experimental stage"). Arauz (2000) also states that in Costa Rican artisanal longline fisheries targeting maji maji, lines are set on the surface and are left to soak during the day.

- In a ranking of methods for reducing seabird bycatch that included: thawed bait, dyed bait, underwater release chutes, side-setting, weighted branchlines, the bait pod and circle hooks, underwater setting chutes, night setting, fish oil, bait placement, line shooters, thawed bait and strategic offal discharge, Melvin and Baker (2006) ranked blue-dyed squid the least effective method.

- Despite some success in laboratory experiments testing blue-dyed bait on Kemp's ridley (*Lepidochelys kempii)* and loggerhead turtles (*Caretta caretta)*, Swimmer *et al*. (2005), once aboard commercial fishing boats in the Gulf of Papagayo, Costa Rica concluded that dyed bait in the field did not reduce turtle interactions in those longline fisheries. In the laboratory, testing red-dyed squid, Kemp's ridley turtle actually preferred the red-dyed squid to the untreated squid (which was preferred by the captive loggerheads.)

- Studying the effect of dyed and non-dyed baits of mackerel and squid on bycatch of loggerhead turtle *Caretta caretta* in a pelagic longline fishery in the western North Pacific, Yokota *et al.* (2009) discovered that the bait color had no effect. Using mackerel rather than squid bait, on the other hand, was very effective, with catch rates of loggerhead predicted by the models being 75% lower with the mackerel bait. Similar model analyses were also performed on target and by-product fish species, such as swordfish *Xiphias gladius*, striped marlin *Tetrapturus audax*, bigeye tuna *Thunnus obesus*, blue shark *Prionace glauca*, and shortfin mako shark *Isurus oxyrinchus*. For these species catches, there were no such marked differences between bait species and color.

ACAP's 2007 review on seabird mortality and deterrence Cocking et al.,(2008)'s results, that suggest that dyeing bait is effective if the bait is squid, but not very effective if the bait is fish. Moreover, dyeing the bait on-board, as noted by other observers, imposes labour on the crew and is difficult in bad weather. The group feels that studies of the effectiveness of the method have not yet produced "consistent results". As with other methods, dyeing should be used in combination with bird scaring lines or night setting. Tests are also needed in the Southern Ocean. Regarding specifications, ACAP suggests: "mix to standardized colour placard or specify (e.g. use 'Brilliant Blue' food dye Colour Index 42090, also known as Food Additive number E133, mixed at 0.5% for a minimum of 20 minutes) to thawed or partly-thawed squid." Gilman and Bianca, their review, do not consider dyed bait a viable option for avoiding turtle bycatch (FAO, 2009). According to these authors, the use of fish bait is also much preferable to that of squid to avoid hooking of turtles.

Offal discharge: Offal, consisting of fish remains that are free of fishing gear, can be discarded off the boat to distract bycatch species as far as possible from the area where the lines are being set or hauled. However, there exists an implicit risk of attracting an even greater number of seabird to the fishing area. The method is mentioned in the literature as a way to distract combative seabirds, and appears in the Hawaii longline regulations. It appears to be recommended, however, only under specific circumstances and is not to be considered as generally useful across different fisheries in different regions.

Investigating methods to reduce bycatch of seabirds in a trawling fishery, Abraham *et al.* (2009), after testing various forms of release including puncturing swim bladders and pumping minced offal out in sump water, concluded that retaining the waste was the best strategy. Avoiding the discharge of offal during setting of mid-water longlines is also recommended by the FAO Round Table on Mitigation Measures (Lokkeborg and Thiele, 2004). As noted by Lokkeborg (2008), trawl fisheries report that interactions with seabirds are rare when offal is not being discarded.

Non-fatal interactions between seabirds and hooks also occur when longline catch is hauled aboard (Lokkeborg and Thiele, 2004). Offal discharging is more common during this time, together with streamer lines or a "water curtain" around the hauling window. A "moon-pool" inside a ship, that allows hauling in bad weather, also helps to avoid any contact between seabirds and the line.

ACAP's 2007 review of the literature on seabird deterrence mentions, as it does for side setting, a need to define "offal discharge". Echoing the FAO Round Table on Mitigation Measures, discharge, if required, should be restricted to periods when the vessel is not setting or hauling. Discharging offal "strategically" during the setting of lines is prohibited in CCAMLR fisheries and "should be discouraged" in others. If it is necessary to discharge it, in view of the practical limitations in storing offal on small vessels, it should be done on the side of the ship opposite the hauling bay, and all swim bladders should first be punctured (Lokkeborg and Thiele, 2004). Under CCAMLR conservation measure 25-02 (2005), no. 5 states: "For vessels or fisheries where there is not a requirement to retain offal on board the vessel, a system shall be implemented to remove fish hooks from offal and fish heads prior to discharge." (citing McNamara *et al.*, 1999; Cherel *et al.*, 1996.)

Sensory deterrents for turtles: Southwood et al. (2008), reviewing the literature on possible sea turtle deterrents including olfactory, auditory and/or visual cues, cite work by Mejuto et al. (2005) that suggests that "chemical signatures" in longline baits may significantly effect catch rates of target species. With respect to bycatch, however, and specifically that of sea turtles, Southwood et al. note that no effective chemical deterrent has yet been found for sea turtles. Swimmer et al. (2006) observed that sea turtles will in fact "willingly consume" squid treated with squid and sea hare ink, peppers (capsaicans derived from habenero chili peppers), and "pungent substances". Parallel trials with yellowfin tuna and skipjack tuna with the same treated baits showed the same eager response. Southwood et al. (2008) suggest research that looks into predator scent.

Regarding other sensory-based methods, Southwood *et al.* (2008) note that different species of fish (e.g. striped marlin, yellowfin tuna, bigeye tuna and swordfish) have different capabilities to perceive light, and accordingly hunt at different depths. Noting that both sea turtles and pelagic fishes are highly visual predators, and that longline fishing gear likely attracts them more by sight than by smell, the authors suggest that blue and green light sticks used to attract target species to bait should be replaced with light sticks less attractive to turtles. Witzel (1999) also noted that both loggerhead and leatherback capture rates were higher when light sticks were used, possibly because the light sticks resemble the leatherbacks' "bioluminescent glutinous prey". The use of light sticks is currently prohibited in the Hawaiian longline fishery. Southwood *et al.* (2008) suggest modifying the physical design of the light sticks to have them shine mostly downwards to reduce turtle attraction.

Witherington and Bjorndal (1991) showed that loggerhead hatchlings avoid light within the spectral range of 560 to 600 nm (wavelengths invisible to most longline target pelagic species). In considering the utility of this when designing turtle deterrents, Southwood *et al.* (2008) note that it is unknown whether adult loggerheads retain this spectral aversion. They also observe that leatherbacks, which swim deeper than loggerheads and have dimmer senses of sight, may not detect these wavelengths (citing Eckert *et al.*, 2006), though Eckert *et al.* themselves suggest that varying mitigation measures between day and night would benefit loggerheads, leatherbacks, and green turtles.

UV ‘decoys’ to tempt sea turtles away from longline gear are also mentioned by Southwood *et al.* (2008) . They indicate, however, that these could damage the eyes of the fishers deploying the decoys (citing Zigman 1971).

Shark decoys have been suggested by the NMFS Pascagoula Laboratory’s Harvesting Systems Branch as turtle decoys, and are being investigated by Higgins (2006), and Wang and Swimmer (2007). Shark-like floats or banners, particularly banners made of clear UV-absorbent plastic, should be visible to sea turtles but not to “blue water fishes” (Fritsches and Warrant, 2006, citing Fritsches *et al.*, 2000). However, as Higgins notes, it is not known whether turtles “actively avoid” sharks. Captive-reared juvenile loggerheads did exhibit avoidance behaviour, but Higgins indicates that further research with a larger sample size will be needed to examine that reaction.

Summing up sensory deterrents for turtles as management options, Southwood *et al.* (2008) emphasise use that is tailored to the fishery, season, and time of day, as well as to the size and age class of turtles likely to be in the area. Moreover, any sensory stimulus introduced into the pelagic environment, they note, could impact other species.

Sensory deterrents for seabirds: Pierre and Norden (2006) investigated olfactory deterrents to seabirds (including the “globally vulnerable” black petrel, Procellaria parkinsoni) in the New Zealand longline fishery by dripping liver oil of the school shark (Galeorhinus galeus) onto the sea behind the vessel. The treatment reduced both the numbers of seabirds and the number of dives on the baits. The authors suggest research into other seabird species, the active ingredients of the oil, as well as possible habituation of seabirds to it. No mention was made of the possible spectral effects of the oil sheen.

Sensory deterrents for sharks: Following on the evidence that rare-earth magnets and metals can be used to deter sharks (Stroud, 2006), Tallack and Mandelman (2009) studied the incorporation of the rare-earth metal cerium/lanthanide alloy ("mischmetal") into longlines and rod-and-reel gear as a possible deterrent to bycatch of Spiny dogfish (Squalus acanthias) in the Gulf of Maine. No significant reductions, however, were recorded for either gear modification.

Kaimmer and Stone (2008), also seeking a deterrent for Spiny dogfish bycatch on demersal longlines, showed, in the laboratory, that baits incorporating cerium mischmetal suffered fewer attacks from spiny dogfish, and in a field study with the halibut fishery near Homer, Alaska, found that fewer dogfish were caught on hooks with mischmetal than on the other treatments. However, there was no increase in halibut catch that would compensate for the cost of using the mischmetal hooks, which also tend to corrode more quickly.

Gillnet gear modifications

Evidence of high levels of seabird entanglement and death in gillnets has been presented by DeGange and Day (1991) and Uhlmann, Fletcher and Moller (2005) (FAO 2008b). However, data on specific fisheries impacting diving seabirds species such as alcids, penguins, sea ducks, shearwaters, cormorants and gannets is not common. In the absence of such data, less research has been conducted into suitable mitigation for gillnet fisheries than longline fisheries (FAO, 2008b, citing Melvin, Parrish and Conquest, 1999). Revill, writing for CEFAS in 2003, noted that no effective technology to prevent diving birds from entanglement in gillnets appeared to be available at that time, and in 2008 that mitigation was still “in its infancy” (Lokkeborg 2008). Diving seabirds can be found entangled in gillnets at depth, but they can also be entrapped during the setting or hauling of the nets (Lokkeborg 2008).

In the Puget Sound (Washington, USA) drift gillnet fishery for sockeye salmon, non-treaty fishers must use "visual barriers" at the top of their mesh sets and must stay out of areas where sensitive seabird species are most common; however, treaty tribes and Canadian fishers are not bound by this regulation (Harrison, 2001). In central California, gillnets must be set at depths where seabirds and other marine wildlife are not usually found (FAO 2008b).

Seabird mortality in gillnet fisheries was not addressed by IPOA–Seabirds (International Plan of Action/National Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries, adopted in 1999) until very recently — March 3, 2009 (Birdlife International 2009). This follows the acknowledgement by the FAO Committee on Fisheries (COFI) at its twenty-seventh session in March 2007, that the range of fishing gears covered by IPOA–Seabirds had to be extended from longlines "to other relevant gears" (FAO 2008b).

BYCATCH REDUCTION MECHANISMS EMPLOYED FOR GILLNETS INCLUDE:

White mesh panels

Fitting the upper part of a gillnet with white mesh panels, also called bird panels, can make the net more visible to diving seabirds and marine mammals and in theory help them to avoid it. In view of diminished visibility after dusk, pingers may also be used with the modified nets where possible and where practical (Melvin *et al.*, 1999).

Melvin *et al.* (1999) experimented with bird panels to reduce seabird bycatch (primarily Common murres (*Uria aalge*) and Rhinoceros auklets (*Cerorhinca monocerata*) in the Puget Sound fishery, without decreasing sockeye catch or increasing the bycatch of any other species. Although auklets have been observed to dive to 60 m (Burger *et al.*, 1993) and murres to at least 180 m (Piatt and Nettleship, 1985), most of the seabirds caught were entangled close to the surface, as observed by local fishers. The researchers found that making the top 1.8 m of a net more visible had no effect on sockeye salmon catch, whereas making the top 4.6 m visible reduced the catch. Murre bycatch was similarly reduced by 45% with either the shallow or deep visible panels, but auklet bycatch was only significantly reduced (42%) with the deeper panels. However, the researchers recommend combining the use of the shallow panel with other strategies, including avoiding fishing at dawn and dusk (when bird bycatch is highest) and focussing on fishing during higher salmon densities (when birds appear to be more scarce). In this fashion, they feel that the suggested combination of measures could reduce seabird bycatch by up to 70-75% without diminishing catch efficiency for the salmon. They also believe these tools are transferable to coastal gillnet fisheries worldwide.

Gillnets modified for greater acoustic reflectivity

Mooney *et al.* (2004), concerned with the coastal stock of the mid-Atlantic bottle-nose dolphin (*Tursiops truncatus*) and the Gulf of Maine harbour porpoise *(Phocoena phocoena*) tested the acoustic reflectivity of a net enhanced with barium sulphate using simulated dolphin echolocation clicks. While the modified net was more reflective than a nylon net at angles greater than normal incidence but less than 40° at 0°, no difference in target strength was found, and at angles greater than 40° the echoes off the nets blended into the background noise. The researchers concluded that both *T. truncatus* and *P. phocoena* should be able to detect the experimental nets from further away than nylon nets, but that *P. phocoena*, because it has "lower source level echolocation signals, may not detect either net…in time to avoid contact."

Cox and Read (2004) monitored echolocation behavior of harbour porpoises (*Phocoena phocoena)* around normal commercial and barium sulphate - enhanced gill nets in the Bay of Fundy (Canada). They concluded that porpoises do not respond to the acoustic reflectivity of the modified nets, but rather to other characteristics, such as increased stiffness. This was further explored by Koschinski *et al.* (2006) in a fjord on Vancouver Island (Canada). Here they determined that the barium sulphate-treated gillnets were echolocated by the porpoises more than four metres further away than standard nylon nets. However, since porpoises do not always echolocate, and thus may still run into the nets, the researchers suggest that adding acoustic alarms to the nets may increase effectiveness.

- Testing the reactions of harbour porpoises to iron oxide – treated gillnets in the Danish North Sea bottom-set gillnet fishery, Larsen *et al.* (2007) found no significant differences in "acoustic target strengths" between the iron-oxide and conventional gillnets. However, cod *(Gadus morhua)* catch rates in the stiffer nets were lower by about 70 percent. The authors also concluded that the lower catches of both cod and harbour porpoise were due to the mechanical properties of the iron-oxide nets*,* primarily the stiffness.

- Mooney *et al.* (2007), continuing research into the acoustic reflectivity and stiffness of six net types including barium sulphate, iron oxide-enhanced and control demersal gillnets found that barium sulphate and iron oxide-enhanced nets were more reflective than the control nets. They also noted, like Koschinski *et al.* (2006), that while dolphins should detect these nets in time to avoid contact, porpoises may not. They observed that "all lines lost stiffness when soaked in seawater for 24 h." The barium sulphate nets "proved stiffer and more acoustically reflective" than the iron-oxide treated nets, factors that are "likely important in reducing harbour porpoise bycatch."

Seabirds were also found to suffer less bycatch in barium sulphate nets tested by Trippel *et al.* (2003) in the demersal gillnet fishery in the Bay of Fundy (Canada), the strands of which were dyed pale blue to mask the white barium sulphate. A significant reduction of seabird bycatch (primarily greater shearwater) was found in the reflective nets (0.15 birds per net compared to 0.78 birds per control net). The increased visibility of the net was suggested as the factor responsible, as for the white net panels used in Puget Sound. There was no difference in target fish catches, which consisted primarily of cod (Lokkeborg, 2008), but these nets have so far not been refined nor implemented.

Acoustic alarms ('pingers')

Acoustic alarms have been tested for some time in fisheries, almost entirely for deterring marine mammals. A workshop on the interaction of gillnets and cetaceans (Perrin et al., 1994), led to the recommendation by the International Whaling Commission to their world-wide implementation. The mandatory use of acoustic alarms ('pingers') in the Danish cod fishery near shipwrecks (Vinther and Larsen, 2004), in the New England gillnet fishery, in a "spatial–temporal" scheme (Waring *et al.*, 2002), EU vessels of 12m or over, fishing with specified bottom-set nets in the western part of the southern Baltic Sea (ICES subdivision 24) and in the Kattegat and Skagerrak seas (ICES division IIIa), among other areas, are examples of the results (European Commission, 2004). Hareide *et al.* (2005) quote specifically the Council Regulation (EC) No 812/2004, which aims to protect cetaceans. A vessel fishing in Area VIIe,f,g,h and j with 60km of gillnets will "have to have 300 acoustic deterrent devices ("pingers") fitted on the gear at all times."

Melvin *et al.*, (1999) and Olesiuk *et al.*, (2002) suggest that acoustic alarms may be effective in alerting the mammals to the presence of nets, but the same sound may also create the “dinner bell effect” and thus increase depredation of and entanglement in the nets. Habituation and the increased sonar pollution, which can interfere with migration signals, need also to be considered (Carlström *et al.*, 2002). Nevertheless, Cox et. al. (2007) report quite effective reduction of mammalian bycatch in gillnets with the use of pingers, as long as these are maintained and actually used, and indicates that unsubstantiated popular perception that pingers increase depradation or interactions in the Gulf of Maine has lead to the very low compliance rate in the fishing fleet for the use of mandatory pingers.

Pingers can also be used to scare seabirds away from gillnets, either submerged or while being set or hauled (Lokkeborg, 2008 citing Trippel *et al.*, 2003). However, Melvin *et al.* (1999) report that while pingers on monofilament gillnets reduced bycatch of Common murres at rates similar to nets made more visible by white panels near the surface (50%), they had no significant effect on Rhinoceros auklet bycatch. As noted by FAO in their International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (1999), the effectiveness of alarms (distress calls, high volume and high frequency sounds) against seabirds would likely be low, given normal levels of background noise in seabird colonies and on ships and the quick habituation to noises common among seabirds.

- Testing the effects of continuous or responsive pingers on the behavior of bottlenose dolphin (*Tursiops truncates)* in the Shannon estuary, Ireland, Leeney *et al.* (2007) deployed both stationary and moving pingers and used acoustic monitoring devices to monitor for dolphin activity. In the trial of stationary pingers, significantly fewer dolphins were detected in the presence of continuously active pingers than near responsive pingers. In the boat-borne trials of moving pingers, both responsive and continuous pingers appeared to affect the dolphins, causing them to leave the area swiftly and in a straight line*.* Along the east coast of the United States, however, where gillnet fisheries bycatch of bottlenose dolphins exceeds US Marine Mammal Protection Act limits, Cox *et al.* (2004) observed that most of the dolphins in the study area were aware of the net regardless of the alarms. Noting that the alarms can also alert dolphins to the presence of fish in the nets or fish being discarded by the fishing vessel that carries a pinger, the authors recommend more research into the behaviour that causes entanglement.

- In California, an experiment in 1996-1997 on using pingers to reduce marine mammal bycatch in the California drift gillnet fishery for swordfish and sharks found statistically significant bycatch reduction for short-beaked common dolphins and California sea lions. The experiment ended when pingers were made mandatory for this fishery (Barlow and Cameron, 2003).

- In Canada’s lower Bay of Fundy, where localized short-term closures of fishing areas to reduce harbour porpoise *(Phocoena phocoena)* bycatch were considered undesirable by gillnet fishers, acoustic alarms emitting high-frequency sound pulses were researched as an alternative to seasonal area closures. The demersal gill nets fitted with alarms every 100 m along the net floatline reduced the bycatch rates by 77% compared to nets without alarms*.* Although fewer pollock were caught in alarmed nets during one season, the nets with alarms had no noted effect on catch rates of Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*), and pollock (*Pollachius virens*) compared to nets without the alarms (Trippel *et al.*, 1999). Culik *et al.* (2001) carrying out two similar experiments, noted that harbour porpoises in Clayoquot Sound, Vancouver Island, were effectively excluded from a “sonified” area, while herring in the Baltic Sea herring fishery at Rügen Island, Germany, were not affected.

- A 2006 study by Kastelein *et al.* compared the responses of a captive striped dolphin (*Stenella coeruleoalba)* and a harbour porpoise to a pinger. The striped dolphin did not respond to the acoustic signal at all, while the harbour porpoise showed "strong behavioural responses". Kastelein concluded that "source levels of acoustic alarms should be adapted to the species they are supposed to deter, and alarms should be tested on each odontocete species for which they are intended to reduce bycatch."

- Focusing on predation by bottlenose dolphins (*Tursiops truncates)* in the artisanal gillnet (bottom-set) fishery around the Balearic Islands, Borodino *et al.* (2002) concluded that while pingers reduced the rate of net interaction, more had to be known of potential habituation to the pingers by the dolphins. Referring to the Kastelein study and a 2002 study by Carlström *et al.*, Borodino *et al.* concluded that fishery managers in different areas will "require evidence of pinger effectiveness in their particular fishery when making decisions on bycatch mitigation policies." Jefferson and Curry (1996), while acknowledging that alarms have "greatly reduced large whale entrapment in fish traps in Canadian waters", state that the technique has not reduced small cetacean bycatch in some gillnet fisheries and that before acoustic methods have any chance of reasonable and consistent success, marine mammal echolocation behavior with regards to fisheries needs better research.

- In 1991 R.M. Dawson, unpersuaded by arguments for the use of pingers, argued that the number of cetaceans killed in gillnets would best be reduced by closing specific areas to gillnetting. Referring to a 1994 study showing a 92% reduction in bycatch of harbour porpoises in sink gillnets equipped with acoustic pingers, Dawson *et al.* (1998) argued that pingers were practical only where entanglement rates were high and that questions remained concerning pinger effectiveness and deterrence over time and the actual mechanism of deterrence. Size, cost and battery life of pingers were constraints, and cost-effectiveness of monitoring was questionable. Larsen (2004), studying how best to attach pingers to fishing gear in the Danish bottom-set gillnet fishery, found that "low interference with net handling, low cost and long lifetime" were the "most important criteria for the acceptance of pingers among fishermen." Even if the effectiveness of pingers were confirmed, Dawson (1991) argued that their widespread incorporation into gillnet fisheries might still not meet the requirements of the US Marine Mammal Protection Act. Scientists, managers and fishers were therefore urged to explore other options, such as time and area closures and more selective fishing methods*.*

- Studying harbour porpoises in the Baltic, Carlström *et al.* (2009), set out to determine the distances at which pinger sound affected echolocation encounter rate, initial sighting rate and group size. Long-term habituation to the pingers was considered more likely to develop close to the pingers on the simulated net and close to shore, where porpoise density was lower and animals may already have heard several pingers on their way in. The longer the pingers were used, the greater was the delay in return of the porpoises to the area when the pingers were off. While pingers are useful in reducing porpoise bycatch in fisheries that follow a target species in waters sparsely populated by porpoises, they may also affect porpoises at greater distances than previously observed, and can thus keep porpoises from critical habitats. Alternative solutions are therefore suggested for ecologically important habitats and migration routes. Working in the Baleric Isands (north-eastern Majorca), Gazo *et al.* (2008) examined the effectiveness of pingers in discouraging predation by common bottlenose dolphin on bottom nets. Although the pingers did not discourage the dolphins from approaching the fishing nets, those nets that had working pingers were damaged much less (87%) than nets without them. Gazo *et al.* noted no effect on the target species (red mullet), but suggested that use of pingers may have other environmental impacts.

The environmental impacts of pingers are the subject of enquiry by the Sub-Committee on Marine Environment and Ecosystems (SCMEE (SAC-GFCM)), as reported in their 2006 Draft Report, which mentioned a "Specific objective 4: to assess the actual efficiency of pingers (and other ways of mitigating bycatch) and the associated environmental impacts of their use at large scale."

Although noting "very substantial reductions in porpoise catches" in the Celtic Sea from pinger trials using the American Dukane pingers, the Royal Commission on Environmental Pollution (2002), expressed concern with the devices including: effects of environmental pollution on whales and dolphins, an overemphasis on the potential of pingers, the practical difficulties in their use (attachment and battery changing requirements), major problems regarding effective deployment and enforcement, unsupportable extra costs for marginal fisheries in the Celtic Sea, and the actual effectiveness of the devices. Pingers should therefore be used only as an “interim emergency measure” after effective implementation and enforcement have been established. Onboard observers should monitor their effects, and regular meetings of all stakeholders should assess and compare pingers and other mitigation measures. Reducing fishing effort, while researching and developing alternative fishing methods that avoid bycatch, are urged upon fisheries managers as more important priorities.

Cox et al. (2007) assessed the effectiveness of pingers in reducing the cetacean bycatch in gillnet fisheries in the Gulf of Maine and in California. They found that effectiveness in the Gulf of Maine bottom gillnet fishery for groundfish was initially high, reducing annual mortalities from an estimated 2100 by 91% in experimental work. However, subsequent years have seen a significant resurgence of moralities, despite mandatory use of pingers, apparently due to a high degree of non-compliance by fishers (probably over 78%). In California, bycatch of short-nosed dolphins and sea lions was reduced by 85% through the mandatory use of pingers on drift gillnets for thresher sharks. Compliance in this fishery is estimated at 99%, with a 10 fold decrease in mammalian bycatch to about 32 per year. A resurgence in mortalities in the early 2000s was attributed to poor pinger maintenance, rather than other factors. The authors suggest that pingers can be very effective at reducing mammalian bycatch, but that a participatory development of the implementation with the fishing fleet is essential for ensuring compliance.

With regard to acoustic alarms used to alert sea turtles to nets, Southwood *et al.* (2008) observed that sea turtles are “hearing generalists” that detect sounds within a similar range to those detected by longline target species. Sounds generated to keep sea turtles away from gear would also therefore be heard by and possibly deter the target species.

Animal predation sounds

Audio recordings of an animal in distress, or of its predator, have been proposed as a means of deterring individuals of that species from entering into a fishing area. Based on a review of multiple studies, Jefferson and Curry (1996) concluded that this technique was largely ineffective for reducing marine mammal interactions with fishing activity.

Acoustic harassment devices

Acoustic harassment devices emit sounds of sufficient intensity to cause pain or alarm in certain underwater species. Primarily used in aquaculture against seals or harbour porpoises (Olesiuk *et al.*, 2002), these devices may exclude other marine animals from migratory routes or foraging grounds. They should therefore be used "with great care" (Fjällinga *et al.*, 2006).

Gillnet depth

Pamlico Sound (North Carolina) has been closed to large mesh gillnet fishing since 1999 because of turtle mortality. Brown and Price (2005) established that the traditional gillnets set for southern flounder (*Paralichthys lethostigma*) had several features that harmed sea turtles. Firstly, they were approximately 12 feet in height, held up with float corks at the top of the line, and so took up a significant portion of the water column. Secondly, they had "tie-downs", or pockets of webbing to capture ground fish (Williamson, 1998). Brown and Price determined that a "low profile gillnet" only six feet in height and without float corks left the upper part of the water column unobstructed and less likely to intercept turtles. The net also had no tie-downs, which eliminated turtle entanglements. The modifications "greatly reduced if not eliminated" the potential for sea turtle bycatch in the fishing grounds off Pamlico Sound. Mostly because of the elimination of the tie downs, flounder catches were 75% of those in the traditional gillnets, but this was acceptable to the commercial fisheries (Price, 2007). In three years of testing (2001, 2004, and 2006) there were 18 sea turtle interactions in 445,500 yards of observed deep-water gillnet sets, experimentally paired with traditional nets. Fifteen of the encounters were in the traditional net and three in the low profile net. The reduction in sea turtle bycatch was found to be statistically significant (Price, 2007).

Nets set below the normal diving ranges of seabirds may also reduce seabird entanglement. However, observers note that seabirds may still be found in these deep nets if they happen to be caught during the setting of the net (Lokkeborg, 2008). Melvin *et al.* (1999) cite a study by Hayase and Yatsu (1993), of the high seas drift gillnet fishery for flying squid (*Ommastrephes bartrami*), which normally tows the nets along the surface. Submerging gillnets to just under 2 m below the surface did significantly reduce entanglement by seabirds, but also diminished the "fishing efficiency" by up to 95 percent.

BYCATCH -SPECIFIC SUMMARIES AND SUPPLEMENTS

Seabirds

To reduce seabird bycatch near Hawaii, regulations require longline tuna (deep-setting) vessels north of 23 degrees North latitude to "use a mainline shooter if the vessel is using a monofilament mainline; attach a minimum 45 g of weight to the branch line within 1 m of the hook; use thawed bait dyed blue to a specified darkness"; and, while setting or hauling longline gear, to discharge fish and offal on the opposite side of the boat. In the Canadian Pacific groundfish fishery, vessels also are required to discharge bait and offal in a manner to not attract seabirds to fishing hooks and vessels must also use bird-scaring lines "depending on vessel size and location" (DFO 2009 & 2010). Melvin and Baker (2006), presenting their summary workshop report (Washington Sea Grant program) on seabird bycatch mitigation in pelagic longline fisheries, repeat the importance of using combinations of measures. In judging specific methods, they rank the highest priorities for future research as streamer lines (or bird-scaring lines), the bait-setting capsule (see Smith and Bentley 1997) and side-setting. Weighted branch lines, the bait pod and circle hooks were ranked as secondary priorities. Underwater setting chute, night setting, fish oil, bait placement, line shooters, thawed bait, and strategic offal discharge were all ranked "low". Blue-dyed squid was ranked lowest.

Under the regulations, hooks must also be removed from fish and spent bait before discarding, a specified quantity of blue dye must be kept onboard, and a specific protocol to handle captured Short-tailed albatrosses must be followed (Abraham *et al.* 2009).

As reported in ACAP (2007), CCAMLR chose to adopt various methods to reduce incidental mortality of seabirds in longline fishing operations, listed in order of priority in Appendix 2. The highest priority strategies all recommend using weights to sink line quickly out of reach of seabirds. Setting at night, using bird deterrent devices and bait and offal management are recommended. Cox et al. (2007) indicates that this combination of mitigation measures has reduced bird bycatch by over 99% in the South Georgia toothfish fishery, comparing 2005 with 1992. These authors feel that the dedicated compliance by the fleet of 19 vessels was essential in achieving this result, fruit of a very transparent and collaborative implementation strategy and stringent licence requirements.

In the 2008, FAO workshop to follow-up on the 1999 recommendations on reducing bird bycatch, highlights the recent Chilean development of "umbrella" net-sleeves as a very promising complimentary approach, not yet dealt with in the CCAMLR referenced work (Moreno *et al.* 2007)

Marine mammals

On a global scale, gillnets have been considered one of the main causes of cetacean mortality attributed to interactions with fishing gear. This concern stimulated a conference on cetaceans and gillnets sponsored by the International Whaling commission (Perrin et al., 1994). Resulting from this conference, acoustic pingers on gillnets became mandatory in several locations (see above) and the "GloBAL" research network based at Duke University was created. Cox et al. (2007) review the effectiveness of some of the bycatch reduction measures implemented in a variety of fisheries in the time since 1994, concluding primarily that technical innovations can be quite effective, but only if compliance and monitoring in the fishery exists. The authors feel that this compliance is only achieved through truly participatory development of mitigative measures with the fishing industry.

Sperm whales began to impact the Alaskan demersal longline fishery for black cod (*Anoplopoma fimbria*) in the 1970s. Findings of the SE Alaska Sperm Whale Avoidance Project (SEASWAP), which uses passive acoustic techniques to track the animals, indicate that in the absence of fishing vessels, sperm whales forage at mid-depth in the water column (e.g. 250 m in 500 m deep water). When longline vessels begin to fish, the sounds they make attract whales within a radius of ten miles. The attraction seems related not to the sounds of the longline equipment, but to how the vessel is handled during the longline haul (Thode *et al.* 2005).

Gilman *et al.* (2006b) suggest methods to mask longline vessels' sounds and appearance to avoid cetaceans. Fleets can steer away from "hotspots" where whales may suddenly appear in large numbers; underwater acoustic devices could mask setting and hauling sounds and the sounds of the vessels themselves; the captured fish on the longlines could be wrapped or "encased" to keep cetaceans from noticing them or getting at them, and the bait and gear could be somehow given an unappealing smell or taste (to the cetaceans); decoy sounds played throughout the fishing grounds could distract cetaceans from the actual fishing vessels; acoustic devices could mask returning cetacean echolocation signals, and "tethered sono-buoys" that track cetaceans could allow the fleet to steer clear of whale concentrations. The authors also suggest that vessels known to have low encounters with cetaceans be examined to see where they differ in design and operation from vessels with high interaction rates. Moreno et al. (2007) describe the development of "Umbrella nets" in the Antarctic and

Chilean fisheries that have been described in the FAO 2008 bycatch symposium as highly effective against sperm whale depradation.

Possible methods suggested by Dahlheimer (2006) to help reduce killer whale (*Orcinus orca*) depredation on black cod caught on longlines include using “sparker devices” that emit flashes of light and sound to startle whales; rubber bullets, as “irritants”; electrical currents; playing back recorded sounds from longline operations to weaken the association of the sounds with food; bubble screens to interfere with “active/passive acoustical sense or vision of whales; skiffs deployed from main vessel to harass the whales visually and acoustically; sonic devices in frequency range that is irritating to whales; lithium chloride/ether to produce a vomiting reaction in the whales, and “operant conditioning” to modify whale behaviour (a weak signal would “precede a strong, aversive signal”). Management solutions would include modified gear, using pot gear instead of lines, seasonal restrictions or fishing in an area when killer whales are largely absent, and closing fisheries in areas with high levels of depredation.

However, decoy boats, blank sets, combined hauling, night fishing, short movements of under 60 nautical miles, electrical current, tangle imitators and “bang pipes” were not very effective in deterring killer whales from longlines and nets in Alaska, where about 25% of the sets in a season lost up to 80% of their catch to the whales (Dahlheimer 2006). Moving fishing vessels more than 60 nautical miles, stopping operations and dummy buoys had ‘”some effect”. Switching target species to Pacific cod was “very effective”, as was the use of trap gear. Explosives and acoustic harassment were not tested. Fishers reported that “shooting, seal bombs, and other techniques” were also ineffective in driving away the whales, which had learned to associate the boats with food.

Gouveia (no date), working in the US Northeast, suggests research into lowering groundlines to depths "other than the ocean bottom" in order to avoid large whales. Information on the distribution and foraging behaviour of the prey of large whales as well as on methods to reduce the profile of groundlines is needed.

Turtles

Gilman *et al.* (2007c) state that “because most research has been initiated only recently, many results are not yet peer-reviewed, published or readily accessible. Moreover, most experiments have small sample sizes and have been conducted over only a few seasons in a small number of fisheries; many study designs preclude drawing conclusions about the independent effect of single factors on turtle bycatch and target catch rates; and few studies consider effects on other bycatch species.”

Gilman *et al.* (2006a) suggest turtle avoidance strategies must be assessed for viability and cost for specific fisheries, since much depends on the size and species of turtles and the target species. Longline fleets that use shallow-set gear, those that interact with the most threatened turtle populations and those that fish near waters with high densities of turtles, i.e. near breeding colonies, are identified as the highest research priorities for trials.

Other strategies being assessed (Gilman *et al.*, 2006a) include: “(i) using small circle hooks (# 4.6-cm narrowest width) in place of smaller J and Japan tuna hooks; (ii) setting gear below turtle-abundant depths; (iii) single hooking fish bait vs. multiple hook threading; (iv) reducing gear soak time and retrieval during daytime; and (v) avoiding bycatch hotspots through fleet communication programs and area and seasonal closures.”

Watson *et al.* (2005) also noted that sea surface temperature has a “highly significant” effect on sea turtle longline bycatch. A 0.6 °C increase in the sea surface temperatures (in the western North Atlantic Ocean) correlated with an increased catch rate of 14–22% of leatherbacks and a 25-35% increased catch rate of loggerheads. Swordfish, on the other hand, prefer slightly cooler water. The authors suggest that by shifting to cooler waters, sword fisher boats could reduce turtle interactions without affecting swordfish catch. Such a shift would also reduce the bycatch of blue shark, but the authors also note that bigeye tuna catch would decrease in cooler waters.

Arauz (2000) suggests satellite telemetry to study the survival of sea turtles released after being hooked by artisanal longliners off Costa Rica. Improved methods of removing hooks from the jaws and mouths of turtles are also a factor in improving post-release survival (Watson *et al.*, 2005).

Gilman and Bianchi have recently compiled this information into a “Guidelines” document for fisheries managers and practitioners (FAO, 2009). For longlines, they suggest the use of large circle hooks with low offset, whole fish bait, setting hooks lower in the water, reduced soak time, and retrieval early in the day. For gillnets, reduced profile of nets, and longer or no “tie-downs” of demersal nets were key factors for reducing turtle bycatch. In addition, the authors recommend development and training for safe release of turtles, avoidance of turtle interaction “hot spots”, effort management to cap bycatch, observer monitoring coverage, and collaboration with fishing fleets to ensure effective implementation of measures.

Brazner and McMillan (2008) suggest that the substantial estimated bycatch of immature loggerhead turtles in the Atlantic Canadian swordfish and tuna longline fisheries could be mitigated by fishing in water colder than 20ºC, and using fish bait on circle hooks, size 18 or larger.

Sharks

A study by Gilman *et al.* (2007c) of 12 pelagic longline fisheries from eight countries revealed a range of measures to avoid sharks, each reflecting specific economic disadvantages or advantages. Certain fishing areas were avoided, fishers moved on where interactions were high, fish replaced squid as bait and the bait was set deeper. Equipment designed to discard sharks automatically could improve shark survival after release, reduce gear loss and improve crew safety.

Watson *et al.* (2005), working with pelagic longline fisheries in the Western Atlantic, found that blue shark catch rate fell by 9.7% – 11.4% with every 0.6 °C increase in sea surface temperature, depending on the treatment comparison. With some caveats, the effect of daylight soak time was highly significant, leading to an increase in the catch rate of 16% with every 30 min increase in daylight soak time.

Other fish – examples

White sturgeon of the lower Fraser River in BC, a “species of concern” with respect to conservation goals, are caught as bycatch in both drift and fixed gillnets that are fishing for salmon. Education of both the gillnet fishers and active volunteer recovery teams have increased the recovery and survival of captured fish, through both improved untangling protocols and floating recovery tanks. This process is led by a community group, the Fraser River Sturgeon Conservation Society and local First Nations people. Relatively high mortality is still observed for bycatch in the fixed gillnet gear, which is being studied (Robichaud *et. al* 2006).

In the late 1990s and early years of the current decade, there was considerable interest and a specific funding program to increase the selectivity of salmon fisheries in BC, Canada, including that of the gillnet fleet. The goal was to enable continued fishing of stable salmon stocks while avoiding endangered stocks or species (such as coho) (DFO, 2002). A substantial coalition of gillnet associations, universities, and government investigated options and developed a toolkit that is still being perfected. Some positive results were achieved by using multi-twine mesh, entanglement nets, and recovery tanks to improve the survival of coho bycatch from 30 to 95% (e.g. Buchanan *et. al* 2002), and some success in selective capture was observed by adjusting the depth of nets and time of day of fishing to take advantage of species-specific migration behavior (DFO and Fisheries Renewal B.C. 2000). However, the best results are still achieved by tracking the movement of schools of the stocks or species to be avoided, and managing fisheries closures appropriately.

CONCLUSIONS

While there are some publications dealing with the effects of fisheries on what may be genetic biodiversity of target species, "biodiversity" and "ecosystem" impacts are primarily considered as bycatch and habitat impacts in the literature.

Bottom gillnets are considered to have considerable bycatch issues on the European coast and in North America. In eastern Canada, marine mammals and birds are of primary concern (Fuller *et al.* 2008). In both locations, and the Emperor Seamount/Hawaiian shelf, there is also some concern about damage to corals and other benthic invertebrates. The Canadian examples are considered to have high impacts on groundfish and medium high impacts through marine mammal bycatch and damage to coral by Fuller *et al.* (2008). Hareide *et al.* (2005) also express serious concern about "ghost fishing" of lost gear. Modifying how and where gear is fished appear to be the best mitigative measures available to address these impacts, though acoustic deterrent devices may be effective at reducing mammalian bycatch. As indicated by Cox et al. (2007), Osinga et al. (2008) and others, collaboration with the fishing industry is important to achieve this effectively.

Pelagic gillnets are not considered to have significant habitat impacts. However, at the scale of high-seas driftnets, they are recognized to have very serious issues with bycatch – also without effective gear modification opportunities to resolve them. The driftnet fishery is now largely illegal (possibly still significant), but limited legal versions still exist in some parts of the world. In Canada, the smaller midwater or surface gillnets used in a variety of fisheries (also called driftnets in some contexts or locations if not anchored, as are set nets) have documented bycatch issues primarily with finfish, seabirds, and small marine mammals. Favourable net design, operator training and recovery boxes have shown promise in improving the survival of finfish bycatch, coloured top net panels show some promise in reducing the bycatch of some seabirds, and acoustic deterrent devices appear to reduced mammalian bycatch in some situations, but management protocols remain as the main mitigative measures to reduce impacts.

Both bottom and pelagic longlines have a well-documented and researched issue of seabird bycatch, particularly with several endangered species. However, a combination of gear modifications and handling protocols now show great promise in resolving or greatly minimizing this issue – in particular, bird streamer lines, weighted mainlines, and net sleeves have shown considerable effectiveness, particularly if combined with night-setting, or side-setting of gear and control of offal dumping (see Appendix 2). Both pelagic and bottom longlines have some issues with fish bycatch. Fish bycatch does not appear to be easily solved with gear modification, though hook and bait selection may have some effect.

Appropriate management and fishing choices appear to be the main mitigative measure to reduce this factor. Mandatory retention of fish bycatch is one strategy that may be helping in Norway and Canada.

Pelagic longlines also have particular issues with turtle and shark bycatch, in Canada limited to the east coast. Turtle bycatch has been reduced significantly in most areas with the introduction of appropriately sized circle hooks, also with improved survival of hooked turtles (together with appropriate training of users), although Carruthers et al. (2009) found no benefit to loggerhead turtles. The use of fish bait, rather than squid bait, also appears to make a significant difference. Shark bycatch remains a management issue, in many jurisdictions complicated by the high value of shark finning.

Both pelagic and bottom longlines have some issues with marine mammal depradation or bycatch. Net sleeves over the hooks appear to resolve the issue in some locations (e.g. with sperm whales), but in other cases (e.g. with killer whales off Alaska) avoidance appears to be the main mitigative strategy.

Pelagic longlines have no significant issues of habitat damage, but bottom longlines can cause significant damage to sensitive habitats through entanglement. Management of areas to be fished appear to be the main mitigative strategy for this problem.

In terms of impacts on Vulnerable Marine Ecosystems (VME), the majority that are recognized by international bodies are deep-sea environments. Key features that these have in common are presumed long recovery times to impacts and low levels of scientific understanding. Shallower-water sensitive habitats may also be equally important to consider. The main VMEs currently being impacted by gillnets are seamounts in the Emperor Seamount/Hawaiian shelf area and *Lophelia* deep-water corals. Benthic longlines also affect the *Lophelia* coral regions, sponge reefs, other seamounts and potential deep oceanic shelf regions. Management protocols appear to be the only mechanism to mitigate these threats, with international protocols currently being drafted.

Management solutions to biodiversity and ecosystem issues generally now cite a few common elements:

- Collaborative development with users and other stakeholders to ensure practical and enforceable solutions
- Ecosystem approaches
- Marine protected areas or similar as one possible solution

Stated current Canadian policies reflect all of these. Public pressure from civil society, represented by non-profit organizations and consumer groups, broaden the management interest from sustainable resource extraction to conservation interests with broader goals, helping to drive policy development towards these concepts.

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APPENDIX 1: GLOSSARY AND ACRONYMS

ACAP Agreement on Conservation of Albatrosses and Petrels

ASFA Aquatic Science and Fisheries Abstracts

Biodiversity Defined by the Biodiversity Convention Office as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems".

Bycatch Defined by FAO as the "part of a catch of a fishing unit taken incidentally in addition to the target species towards which fishing effort is directed. Some or all of it may be returned to the sea as discards, usually dead or dying."

CCAMLR Convention on the Conservation of Antarctic Marine Living Resources

CEFAS Centre for Environment, Fisheries and Aquaculture Sciences

CITES Convention on International Trade in Endangered Species of Wild Fauna and Flora

CPUE Catch per unit effort

CSAS Canadian Science Advisory Secretariat

DFO Department of Fisheries and Oceans Canada

EAF Ecosystem Approach to Fisheries. Defined by FAO as "an approach to fisheries management and development that strives to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries. The purpose of EAF is to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems."

FAO Food and Agriculture Organization of the United Nations

Fishery Defined by FAO as "an activity leading to harvesting of fish. Or, a unit determined by an authority or other entity that is engaged in raising and/or harvesting fish. Typically, the unit is defined in terms of some or all of the following: people involved, species or type of fish, area of water or seabed, method of fishing, class of boats and purpose of the activities."

Gillnet Demersal (or bottom) gillnets consist of a wall of webbing that hang in the water vertically and is anchored or attached by weights to the seafloor. Fish and other animals get wedged or gilled or tangled in the nets. Nets can vary in length from 100 to 200 metres, and in height from 2–10 metres. Nets can be attached together forming one long string of nets that can reach up to 2,000 metres in length (FAO, 2007).

Pelagic (or midwater) gillnets hang in the water column and do not contact the seafloor. The gear is held vertically in place by anchors or weights attached to the bottom of the net. The depth at which the nets are set depend on the target species (Fuller *et al.*, 2008).

IATTC Inter-American Tropical Tuna Commission
ICES International Council for the Exploration of the Sea
IOPA International Plan of Action
IUCN International Union for Conservation of Nature
Longline Longlines consist of a mainline or groudline. Leaders or snoods (short lengths of line) and baited hooks branch off the mainline at regular intervals and hooks. Each end of the gear is held in place by anchors and has a line attached to a surface buoy. About 3,000 baited hooks can be set on pelagic longlines, that can stretch for a distance of up to 100 kilometres. Demersal longlines are shorter, up to 15 kilometres in length, but can deploy up to 20,000 hooks per set (DFO, 2007a).
MBED Mammals and Birds Excluding Device
NAFO Northwest Atlantic Fisheries Organization
NMFS National Marine Fisheries Services
NOPA National Plan of Action
PICES North Pacific Marine Sciences Organization
PIFSC Pacific Islands Fisheries Centre
Project GloBAL Global Bycatch Assessment of Long-lived Species
SCMEE Sub-Committee on Marine Environment and Ecosystems
UNGA United Nations General Assembly
VME Vulnerable marine ecosystem. Defined by FAO as "areas that are easily disturbed by human activities, and are slow to recover, or which will never recover. Marine ecosystems may be easily disturbed if: (1) they are characterised by low-levels of natural disturbance and / or low levels of natural mortality; (2) component species are fragile and are easily killed, damaged or structurally or biologically altered by human impacts, in this case mechanical disturbance by fishing gear; (3) distribution is spatially fragmented with patches of suitable habitat that are small in area and "rare" in comparison to the overall area of seabed; or (4) important ecosystem functions are disrupted or degraded."
WWF World Wildlife Fund

APPENDIX 2: CCAMLR PROTOCOLS FOR MINIMIZING SEABIRD BYCATCH

As reported in ACAP (2007), CCAMLR chose to adopt various methods to reduce incidental mortality of seabirds in longline fishing operations, listed in order of priority as follows:

1. Fishing operations shall be conducted in such a way that hooklines sink beyond the reach of seabirds as soon as possible after they are put in the water.

2. Vessels using autoline systems should add weights to the hookline ["the groundline or mainline to which the baited hooks are attached by snoods"] or use integrated weight hooklines while deploying longlines. Integrated weight (IW) longlines of a minimum of 50 g/m or attachment to non-IW longlines of 5 kg weights at 50 to 60 m intervals are recommended.

3. Vessels using the Spanish method of longline fishing should release weights before line tension occurs; weights of at least 8.5 kg mass shall be used, spaced at intervals of no more than 40 m, or weights of at least 6 kg mass shall be used, spaced at intervals of no more than 20 m.

4. Longlines shall be set at night only (i.e. during the hours of darkness between the times of nautical twilight ["Wherever possible, setting of lines should be completed at least three hours before sunrise (to reduce loss of bait to/catches of white-chinned petrels)"]. During longline fishing at night, only the minimum ship's lights necessary for safety shall be used.

5. The dumping of offal is prohibited while longlines are being set. The dumping of offal during the haul shall be avoided. Any such discharge shall take place only on the opposite side of the vessel to that where longlines are hauled. For vessels or fisheries where there is not a requirement to retain offal on board the vessel, a system shall be implemented to remove fish hooks from offal and fish heads prior to discharge.

6. Vessels which are so configured that they lack on-board processing facilities or adequate capacity to retain offal on board, or the ability to discharge offal on the opposite side of the vessel to that where longlines are hauled, shall not be authorised to fish in the Convention Area.

7. A streamer line shall be deployed during longline setting to deter birds from approaching the hookline. Specifications of the streamer line and its method of deployment are given in the appendix to this measure.

8. A device designed to discourage birds from accessing baits during the haul of longlines shall be employed in those areas defined by CCAMLR as average-to-high or high (Level of Risk 4 or 5) in terms of risk of seabird bycatch. These areas are currently Statistical Subareas 48.3, 58.6 and 58.7 and Statistical Divisions 58.5.1 and 58.5.2.

9. Every effort should be made to ensure that birds captured alive during longlining are released alive and that wherever possible hooks are removed without jeopardising the life of the bird concerned.

10. Other variations in the design of mitigation measures may be tested on vessels carrying two observers, at least one appointed in accordance with the CCAMLR Scheme of International Scientific Observation, providing that all other elements of this conservation measure are complied with. Full proposals for any such testing must be notified to the Working Group on Fish Stock Assessment (WG-FSA) in advance of the fishing season in which the trials are proposed to be conducted.

APPENDIX 3: TECHNICAL INNOVATIONS TO REDUCE BYCATCH

From Jennings and Revill, 2007.

Reducing unwanted catches of fish and invertebrates

Larger diamond mesh	Blow-out panels
Escape panels	Headline/footrope manipulation
Square mesh codends/ T90 codends	Sweepless trawl
Grids	Fykenet excluder
Sieve nets	Selective longline hooks
Separator panels	Escape vents, traps, and pots
Cutaway trawls	Benthic release panels
Magnetized gear components to repel elasmobranchs	

Reducing unwanted catches of mammals

Grids	Pingers
Altered float lines	Fykenet excluder
Back down manoeuvre	

Reduced unwanted catches of reptiles

Longline circle hooks
Grids (TED)
Sunken longlines

Reduce unwanted catches of birds

Streamers lines	Setting tubes
Sinker weights	Warp fixed bird scarers

APPENDIX 4. ASSESMENT OF LONGLINE BYCATCH MITIGTION TECHNOLOGIES

Ranking scale: 1 = least favourable, 5 = most favourable (adapted from ACAP 2007)

Mitigation*	Effective for surface feeding birds	Effective for diving birds	Practical	Safe	Capital cost	Operational cost	Applicability to Distant Water/ Domestic fleets	Compliance	Future research priority
Primary									
Streamer lines	4	3	4	4	5	5	5/5	1	5
Weighted branch-lines	4	3	5	1	4	4	5/5	5	4
Underwater setting: Chute	2	1	2	3	2	5	1/5	1	1
Bait setting capsule	5	4	4	4	2	5	5/5	3	5
Bait pod or “smart hooks”	5	4	3	4	4	4	5/5	1	4
Night setting	4	3	5	4	5	3	5/5	3	1
Net sleeves – umbrella hooks**	5	5	5	5	3	5	5/5	4	4
Secondary									
Circle hooks	?	?	5	5	5	5	5/5	5	4
Bait placement/ casting	2	2	5	3	4	4	5/5	1	1
Line shooter	2	2	5	3	4	4	5/5	1	1
Thawed bait	2	2	3	5	5	5	5/5	1	1
Offal discharge	2	2	3	5	5	5	5/5	1	1
Other									
Side setting	2	2	3	4	4	5	5/5	5	5
Blue dyed squid	3	3	3	5	5	4	5/5	1	3
Blue dyed fish	1	1	3	5	5	4	5/5	1	1
Fish oil	1	4	2	4	4	3	5/5	1	2

***** “Primary measures = likely to be effective without other mitigation; secondary measures = considered useful for deployment with other measures; other = early stage of development and/or limited research results to date. Acoustic alarms, water jets, time-area closures, and artificial lures/bait were not considered.”

** Net sleeves were not considered in original table, but have been indicated as very promising in FAO (2008).

APPENDIX 5: ECOSYSTEM IMPACTS OF GILLNETS AND LONGLINES

	Impact						
Gear Type	**Habitat**	**Biodiversity**	**VME impacted**	**Sensitive habitat impacted**	**COSEWIC threatened species**	**Charismatic species**	**Mitigation measures**
Pelagic Gillnet		Bycatch potential			NA Right whale	Birds, whales	Operational*, mesh size, coloured top panels, trot-lines, bycatch revival tanks; pingers
Bottom Gillnet	Entanglement	Bycatch potential, ghost fishing	Seamounts, *Lophelia* reefs			Birds, whales	Operational, mesh size; pingers, reduced fleet size (# joined nets); taut rather than saggy nets; reduced buoy lines; acoustic tags
Pelagic Longline		Bycatch potential			Leatherback turtle	Birds, sharks, turtles	Gear and operational modifications, bycatch revival
Bottom Longline	Entanglement	Bycatch potential	Seamounts, *Lophelia* reefs		Leatherback turtle	Depredation by whales	Regional restrictions, gear and operational modifications, bycatch revival

* "Operational" Includes avoiding areas and times of high concentrations of potential bycatch species, protocols for raising or deploying gear, etc.