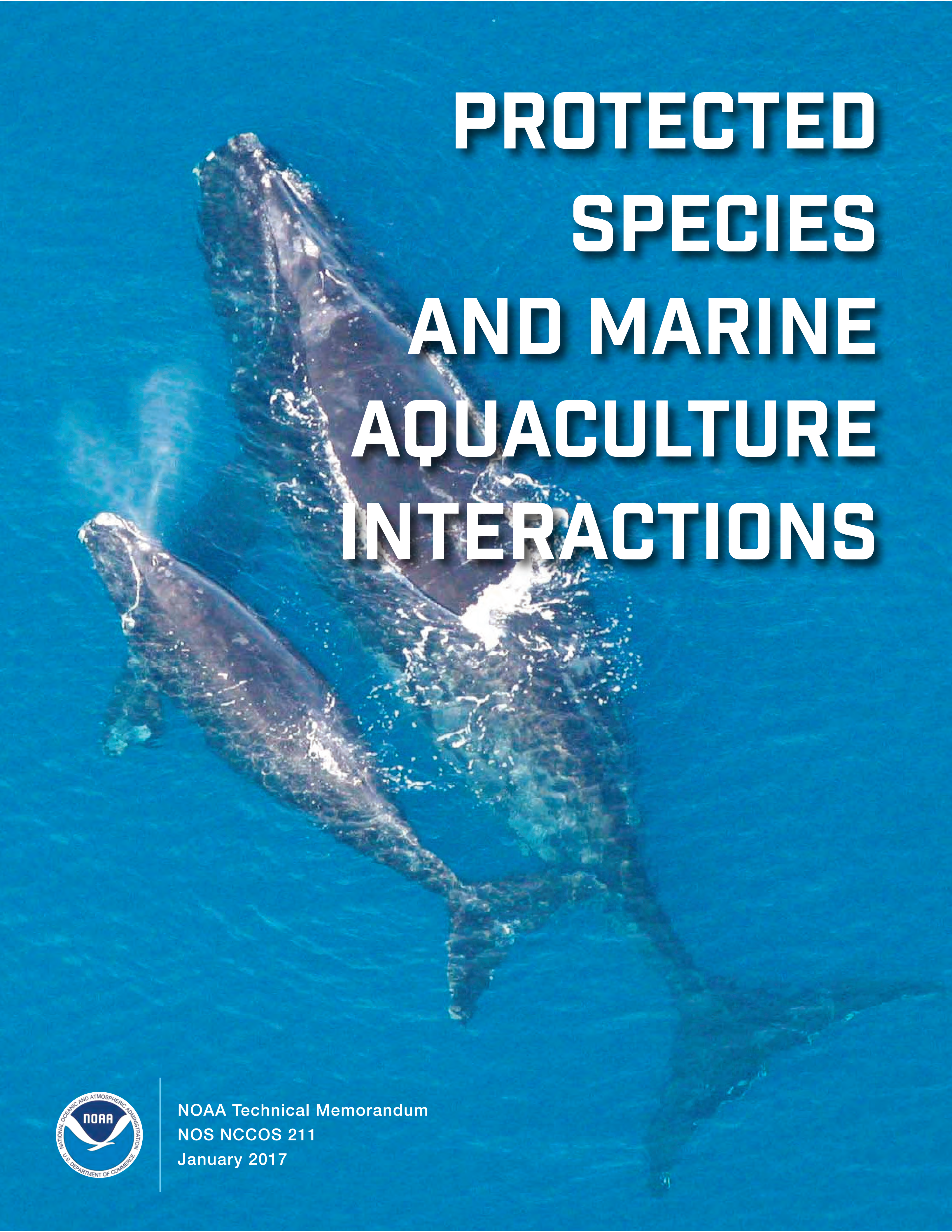

PROTECTED SPECIES AND MARINE AQUACULTURE INTERACTIONS

NOAA Technical Memorandum
NOS NCCOS 211
January 2017

PROTECTED SPECIES AND MARINE AQUACULTURE INTERACTIONS

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January 2017

Green sea turtle

CAROL SEALS PRICE*

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To access this report on the web and learn more about NOAA/NOS/NCCOS Coastal Aquaculture Siting and Sustainability research, please visit: coastalscience .noaa.gov/research/scem/marine_aquaculture.

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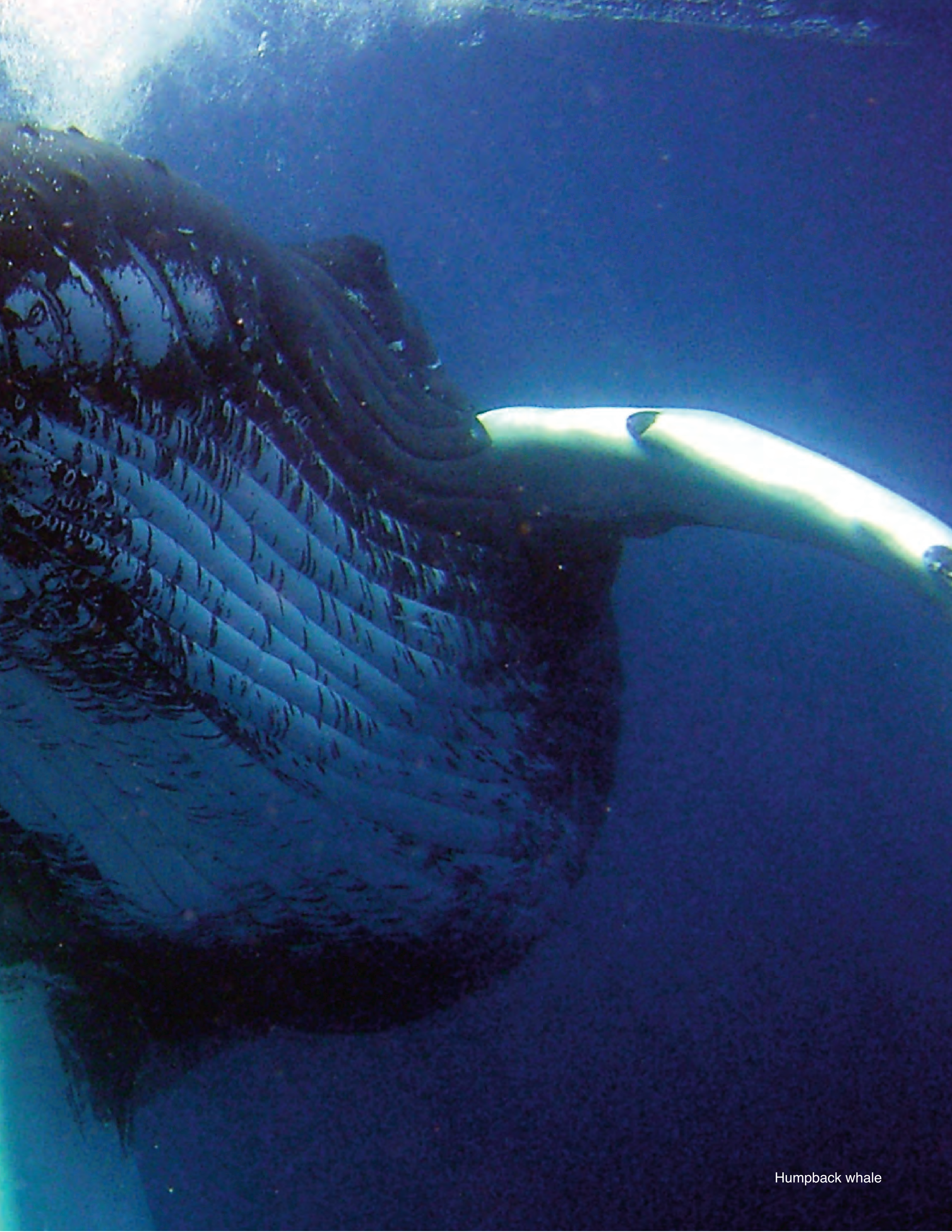
CONTENTS



Humpback whale

EXECUTIVE SUMMARY

Marine aquaculture in federal waters is expected to expand in the United States (U. S.) Economic Exclusive Zone (EEZ) due to increased demand for domestically grown seafood coupled with improved technological capacity to farm in the open ocean. Since the emergence of modern aquaculture, industry and coastal managers have been collecting information on protected species interactions. However, to date there has been no comprehensive summary or analysis available to guide the regulatory process of Protected Resources Division (PRD) consultations to meet the National Oceanic and Atmospheric Administration (NOAA) goal of advancing aquaculture in the open ocean while still meeting its conservation mandates under the Endangered Species Act (ESA).

This global assessment summarizes the current state of knowledge regarding documented and potential interactions of species listed under the ESA, such as sea turtles and marine mammals, and evaluates offshore longline mussel culture gear interactions as a case study. This assessment will strengthen the ability of NOAA and other regulatory agencies to make science-based decisions and recommendations as part of the review and consultation process required to permit aquaculture operations. In addition to providing a state of science analysis, the assessment includes a preliminary risk analysis to evaluate potential for harmful interactions between aquaculture and protected species, identifies knowledge gaps, provides management recommendations, and highlights areas of needed research.

The research and data analyzed for this assessment indicate interactions and entanglements with longline aquaculture gear worldwide are rare and close approaches by protected species are seldom documented. It is unclear if this is because farms are relatively benign and pose little risk, or because the number and density of farms is so low that the detection level for harmful interactions is also small. There remains an overall general lack of scientific reporting on aquaculture-related entanglement frequency and severity of resulting injuries, mortality rates associated with interactions, effective deterrent methods, and technological innovation to reduce interactions and decrease harm if contact occurs. Importantly, negative data—scientifically collected data reflecting the lack of interactions with protected species—is also lacking. This makes it difficult to know if the paucity of reported incidents is due to low numbers of interactions or failure to detect and report them.

Because there are few documented cases of negative interactions of marine aquaculture and protected species like marine mammals, sea turtles and seabirds, regulatory agencies may look to information on interactions between protected species and fishery (wild capture) gear to inform decision making. Marine megafauna, including marine mammals, sea turtles, seabirds and sharks, are known to interact directly with many types of marine gear, including fishery gear. Since some fishery gears, or components of the gear, are similar or analogous to aquaculture gear, it may be appropriate in certain instances to draw similarities between gear types as proxies, when determining relative risks to marine mammals to inform regulatory and management decisions with respect to aquaculture. For this reason, the assessment also includes a review of research on fishery gear interactions with protected species, for the purpose of assessing which lessons learned may be applicable to aquaculture gear.

Preventative measures such as spatial planning to inform siting may help avoid or resolve potential conflicts as the marine aquaculture industry grows. Further research into the mechanisms behind entanglement and other harmful interactions will provide valuable insight into how protected species react to marine aquaculture gear. A more technical consideration of longline mussel aquaculture gear, such as tension strength analysis for backbone lines, will provide useful information for understanding how protected species may interact with farm gear and lead to effective modifications to decrease harmful interactions. Research to better understand how marine species perceive farm structures visually and acoustically will likewise aid in developing strategies to avoid harm. More in-depth analysis to discern which protected species are most prone to entanglement in or collision with aquaculture gear and other marine industries will enhance current efforts to avoid interactions.

The growth of the aquaculture industry in the U. S. and worldwide has drawn attention to the potential environmental impacts of offshore aquaculture, including impacts to protected species. As the scope of aquaculture activities increases in the open ocean, it is important to make decisions about marine aquaculture within an ecological context. The rising world population is becoming more reliant on aquaculture for food production. In the United States, the regulatory process for permitting offshore aquaculture facilities is moving forward and industry growth is expected. Domestic production of seafood can aid in decreasing U. S. reliance on imported products, provide jobs and food security, and meet the rising demand for seafood. Every effort should be made to ensure that this foreseeable industry growth occurs within a framework of environmental responsibility and ocean stewardship.

Deploying mussel spat
lines for grow out

INTRODUCTION

This assessment summarizes the current state of knowledge regarding documented and potential interactions of species listed under the Endangered Species Act as amended (ESA; 16 U. S. C. § 1531–1543), such as sea turtles and marine mammals, with offshore longline mussel culture gear. Its primary purpose is to strengthen the ability of the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) Greater Atlantic Regional Fisheries Office (GARFO) to make science-based decisions and recommendations as part of the review and consultation process required to permit aquaculture operations in federal waters. Although developed in coordination with GARFO staff, this assessment is highly relevant to efforts already underway and upcoming in other U. S. regions to permit longline mussel aquaculture.

The information in this assessment is useful for guiding the regulatory process of Protected Resources Division (PRD) consultations to meet the agency goals of advancing aquaculture in the open ocean while still meeting its mandates under the ESA. In addition to summarizing what is known and providing a state of science analysis, the assessment includes a preliminary risk analysis to evaluate potential for harmful interactions between aquaculture and protected species. It also identifies knowledge gaps and areas of needed research. We gathered relevant publications and data on protected species interactions with specific gear types used in commercial marine aquaculture and explored interactions with similar or analogous fishing gear. We used this information to provide management options to help coastal managers to make informed science-based recommendations about permitting, siting and managing aquaculture in a manner consistent with federal mandates to protect imperiled species, while also supporting the production of sustainably grown seafood.

SPRING BAY SEAFOODS

Background

Marine aquaculture in federal waters is expected to expand in the United States (U. S.) Economic Exclusive Zone (EEZ) due to increased demand for domestically grown seafood coupled with improved technological capacity to farm in remote, open ocean sites (Kapetsky et al. 2013, Kite-Powell et al. 2013, Rust et al. 2014). Globally, there are no conventions for delineating inshore, nearshore or offshore marine aquaculture. For the purposes of this review, we considered a combination of factors including proximity to shore, water depth, type of gear required to operate in a site, scale of the operations, level of exposure, and visibility to the public to define the terms "inshore", "nearshore", and "offshore" aquaculture. Inshore farms are adjacent to the shoreline where environmental dynamics are predominantly tidally influenced. Aquaculture is highly visible and easily accessible from the shoreline. In many places this would include intertidal areas, such as estuaries and lagoons. Many shellfish farms are inshore operations. Inshore farms are often small businesses and, in many countries, provide a significant local food resource for rural coastal communities. Inshore can also be large industrial operations such as large shellfish farms and coastal ponds excavated for rearing seafood. Nearshore farms are less than 3 miles from shore, but not immediately adjacent to the shoreline. Tidal influence may still be apparent, but is less of a factor for farm operations compared to strong flushing currents, winds and ocean circulation. Nearshore farms are found in deeper water and may experience significant exposure. Nearshore farms include many operations found in lochs, fjords and other large embayments providing some sheltering from open ocean conditions. Nearshore farms are visible from the shoreline. These operations tend to be larger scale investments than inshore farms and include both finfish and shellfish. The cage gear and anchoring systems used at these farms may closely resemble that used at offshore operations. Offshore farms are further than 3 miles from shore. Offshore farm sites are in relatively deep water with strong flushing currents. Cage technology must be able to withstand open ocean conditions including winds and waves resulting from storm activity. At some sites, cages may be submersible. These farms will generally be large scale commercial enterprises requiring large capital investment due to the technology costs. Because 3 miles is roughly the distance to the horizon line, offshore farms are likely not visible from the shoreline when standing at sea level. In many U. S. locations, this distance correlates to the boundary between state and federal maritime jurisdiction.

Offshore shellfish culture in the United States is expected to comprise primarily blue mussel *Mytilus edulis* and *M. galloprovinciali* production, with sea scallop *Placopecten magellanicus* and oyster *Crassostrea gigas* culture also gaining interest. Marine finfish species cultured in the United States for over 35 years include Atlantic salmon *Salmo salar*, amberjack *Seriola rivoliana*, yellowtail jack *Seriola lalandi*, white sea bass *Atractoscion nobilis*, cobia *Rachycentron canadum*, striped bass *Morone saxatilis*, steelhead trout *Oncorhynchus mykiss*, halibut *Hippoglossus hippoglossus*, Atlantic cod *Gadus morhua*, pompano *Trachinotus carolinus*, red drum *Sciaenops ocellatus*, black sea bass *Centropristis striata* and others. Offshore seaweed *Porphyra spp* and *Macrocystis spp*.

Right whale with calf

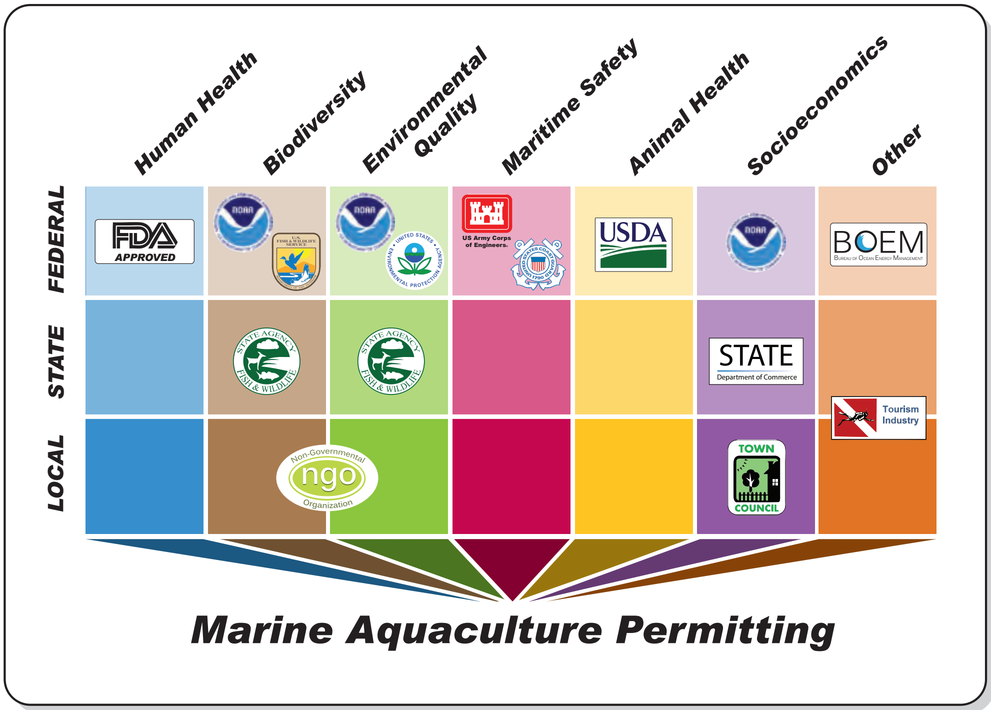


Figure 1. Permitting aquaculture in federal or state waters is a complex process involving consultation with many regulatory agencies and receiving input from diverse stakeholder groups.

aquaculture is also feasible as a stand-alone enterprise or as a component of integrated multi-trophic aquaculture (IMTA; Price & Morris 2013).

The Regulatory Process

Businesses striving to establish a farm must first acquire the appropriate permits. Depending on the location for the proposed site, the type of aquaculture proposed, and the scale of the operation, several agencies may be involved in the permitting process. Other stakeholders may be consulted or may provide comment during permit review (Figure 1). The U. S. Army Corps of Engineers (USACE) is likely going to be the lead agency for permitting offshore mussel aquaculture in federal waters (Otts & Bowling 2012). The USACE must issue a Rivers and Harbors Act Section 10 (33 U. S. C. 403) permit to allow for any construction in or alteration of navigable U. S. territorial waters and to evaluate the environmental effects of aquaculture operations. Section 7 of the ESA requires USACE to initiate consultation with NOAA NMFS on Section 10 permits for impacts on marine resources, such as wild fish stocks, habitat, and protected species. If the U. S. Environmental Protection Agency (EPA) is asked to issue a National Pollution Discharge Elimination System (NPDES) permit, it may be the lead agency and would similarly consult with NOAA.

The listing of a species as endangered under the ESA makes it illegal to take that species, and similar prohibitions usually extend to threatened species, unless exempted under ESA Section 7(a)(2) or 7(d) or Section 10. Under the ESA, take means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in such conduct. All sea turtle and some marine mammal species found in U. S. waters are listed under the ESA. Additionally, all marine mammals are protected under the Marine Mammal Protection Act (MMPA; 16 U. S. C. 1361) which prohibits unauthorized take in U. S. waters. Under the MMPA, take means to harass, hunt, capture, or kill any marine mammal, or to attempt to do so.

Under ESA Section 7, a federal agency undertaking an action ("action agency") must determine if the action may affect ESA-listed species and/or critical habitat in the action area. If the action agency determines that the action may affect these species or critical habitat, the agency must consult under the ESA with NMFS or U. S. Fish and Wildlife Service (USFWS) on the action. A federal agency must "insure that any action authorized, funded, or carried out by such agency . . . is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of [critical] habitat (16 U. S. C. 1536(a)(2))." For actions that may affect, but are not likely to adversely affect ESA-listed species or critical habitat, an informal consultation is completed, and a letter of concurrence is issued. For actions that may affect and are likely to adversely affect listed species or critical habitat, a formal consultation is undertaken to assess the potential impacts of the action to protected species including ESA-listed marine mammals, sea turtles, fish and other endangered or threatened marine life. A formal consultation results in a Biological Opinion. When a proposed activity is likely to adversely affect, but not jeopardize, a listed species or not likely to result in the destruction or adverse modification of critical habitat, the Biological Opinion includes nondiscretionary Reasonable and Prudent Measures and Terms and Conditions to minimize the impacts to listed species. These are mandatory actions that must be undertaken by the action agency for any anticipated incidental take to be exempt from the take prohibitions. For aquaculture projects, the federal action is generally the issuance of a permit from the USACE, which is the action agency.

RELATIVELY LITTLE IS DOCUMENTED ABOUT HOW MARINE MAMMALS AND SEA TURTLES INTERACT WITH AQUACULTURE FACILITIES IN THE OPEN OCEAN.

To make informed determinations of the potential effects of aquaculture activity, PRD scientists rely on peer reviewed publications, technical reports, and expert scientific knowledge. While there is some published data and anecdotal information available from nearshore farms, currently, relatively little is documented about how marine mammals and sea turtles interact with aquaculture facilities in the open ocean, and there has been no summarization of the available information. Due to growing interest in siting mussel longline aquaculture operations in North Atlantic (Maine through Virginia) and other (California) federal waters, NMFS and other regulatory agencies require additional resources to make assessments and knowledgeable decisions about potential interactions with protected species (Table 1). For example, there is concern about potential effects to the critically endangered North Atlantic right whale *Eubalaena glacialis* (Waring et al. 2015) in the North Atlantic.

Additional information is required to better understand the potential consequences of siting aquaculture operations in the region. To this end, a NOAA steering committee (Table 2) was organized to gather, summarize and disseminate the worldwide state of knowledge about effects of offshore aquaculture on protected species,

Table 1 ESA species under NMFS' jurisdiction in the Greater Atlantic Region

Common Name	*Scientific Name*
Atlantic Salmon	*Salmo salar*, Gulf of Maine DPS
Shortnose Sturgeon	*Acipenser brevirostrum*
Atlantic Sturgeon	*Acipenser oxyrinchus oxyrinchus*
Blue Whale	*Balaenoptera musculus musculus*
Fin Whale	*Balaenoptera physalus*
Humpback Whale	*Megaptera novaeangliae*
North Atlantic Right Whale	*Eubalaena glacialis*
Sei Whale	*Balaenoptera borealis*
Sperm Whale	*Physeter macrocephalus*
Green Sea Turtle	*Chelonia mydas*
Hawksbill Turtle	*Eretmochelys imbricata*
Kemp's Ridley Turtle	*Lepidochelys kempii*
Leatherback Turtle	*Dermochelys coriacea*
Loggerhead Turtle	*Caretta caretta*

Table 2 Members of the NOAA steering committee

Name	*NOAA Office*	*Expertise*
Kevin Madley Kevin.Madley@noaa.gov Dave Alves (retired)	NMFS	Regional coordinators for aquaculture in the north Atlantic
Ellen Keane Ellen.Kean@noaa.gov	NMFS	Sea turtle bycatch reduction
David Bean David.Bean@noaa.gov	NMFS	Aquaculture permitting
David Morin David.Morin@noaa.gov	NMFS	Large whale entanglement
Christine Vaccaro Christine.Vaccaro@noaa.gov	NMFS	ESA Section 7
John Kenney John.Kenney@noaa.gov	NMFS	Fishery gear interactions
James Morris James.Morris@noaa.gov	NOS	Environmental effects of marine aquaculture
Carol Price Carol.Price@ncaquariums.com	NOS	Environmental effects of marine aquaculture

SPRING BAY SEAFOODS

Fishermen working with mussel spat

with a specific focus on mussel culture and ESA-listed whales and sea turtles in the northern Atlantic Region. Members of the committee included personnel from the NMFS Greater Atlantic Region's protected resources and aquaculture programs to provide expertise on marine mammals and sea turtles, and knowledge of regional aquaculture activity, and the National Ocean Service (NOS) National Centers for Coastal Ocean Science (NCCOS) Coastal Aquaculture Planning and Environmental Sustainability (CAPES) program specializing in environmental effects of marine aquaculture.

Information about aquaculture infrastructure and gear, and alternative farm management options that could reduce negative interactions is vital. Because there is little direct data, research or observation at open ocean mussel farms, the committee broadened the scope of the assessment to include information about the effects of other marine aquaculture sectors on protected species and other species of conservation concern. Additionally, there was interest in examining possible similarities between fishing gear and aquaculture gear because a great deal of research has focused on fishery[1] gear impacts, and the efforts to redesign gear to be less harmful. Thus, there may be lessons that can be learned and gear modifications that can be transferred to aquaculture structures to decrease opportunities for negative interactions and take of ESA listed species.

Methods

To ensure comprehensive coverage of all available information, we reviewed a range of sources (Table 3). Beginning in Fall 2014, we collected scientific papers, government reports, and books for this review through keyword searches of electronic databases, primarily Aquatic Sciences and Fisheries Abstracts (ProQuest, LLC) and Google Scholar™. To ensure comprehensive coverage, initial searches included broad keyword combinations such as "mussel aquaculture + marine mammal" and "marine fish farming + protected species," which were then narrowed down by carefully reviewing each abstract and full text for direct relevance. Colleagues and early reviewers provided recommendations for additional relevant publications. Unpublished data from operational commercial farms were obtained through direct personal communication.

A draft assessment was prepared and internally reviewed by the NOAA steering committee preceding a workshop held in Gloucester, MA on 28–29 September 2015 (NMFS 2016) that brought together local and national regulators, industry, researchers,

[1] The term "fishery" in this document refers to wild harvest.

Table 3 Sources of information (n=177) cited in this assessment, their relative benefits and drawbacks, and number included in the assessment. Nine sources did not fit into any of the listed categories (e.g., websites).

Sources of Information		
Peer reviewed scientific literature	High credibility Few published studies	74
NOAA Technical Memorandums	High credibility Few published studies	12
Government Reports	Not always peer reviewed Good quality, scientific studies	57
Book Chapters	High credibility Few published studies	6
Non-governmental organization (NGO) publications	May be biased May be qualitative	16
Student Theses & Dissertations	High credibility Few published studies	3

conservation groups and other stakeholders to cooperatively refine the risk analysis and needs assessment included here. The workshop participants were asked to review the draft assessment and their feedback was incorporated.

Expected Outcomes

Science-based determinations during permit review for mussel farms and other aquaculture operations in the north Atlantic and other federal waters throughout the United States will be aided by this assessment. We present a preliminary risk assessment, identify knowledge gaps and suggest management options which may be implemented at offshore farms to reduce harmful interactions with protected marine species. Farm owners and operators can apply these to guide permit applications, siting decisions and farm management practices. Coastal managers and community planners can use this information to make environmentally responsible decisions about the economic opportunities that aquaculture offers. Federal, state, and local regulatory agencies can consider these practices as they develop and implement permitting and monitoring processes for the offshore aquaculture industry. Future coordination of permit review will be successful by having transparent scientifically-informed expectations for guidance from government regulators for their review of permits for marine aquaculture. Finally, we anticipate this work will help understand the broader ecological role of aquaculture operations within the marine environment.

SUCCESSFUL FUTURE COORDINATION OF PERMIT REVIEW WILL BE AIDED BY HAVING TRANSPARENT, AGREED UPON AND SCIENTIFICALLY INFORMED EXPECTATIONS.

PROTECTED SPECIES & MUSSEL LONGLINE AQUACULTURE INTERACTIONS

Introduction

There is ongoing interest building on previous efforts to develop siting and management guidelines to minimize harmful interactions between marine aquaculture and protected species (Moore & Wieting 1999). Historically, there has been little available or published information about how marine mammals, sea turtles, and other protected species interact with aquaculture gear in general, and there is sparse documentation of interactions with marine aquaculture in the U. S. To date there are no reported or published accounts of harmful interactions between protected species at any pilot scale or commercial farms in the offshore waters of the U. S. EEZ waters. Even less is known about the impacts of gear from specific aquaculture sectors, such as the offshore mussel longline industry. This may be partly because there is currently a low density of operational gear deployed in the U. S. However, the expansion of this industry, particularly in New Zealand, provides data to inform permitting and management decisions for mussel operations in the United States. Globally, aquaculture and protected species interactions have been documented in Australia and New Zealand (Lloyd 2003, Clement 2013), the North Atlantic Ocean (Johnson et al. 2005), Chile (Heinrich 2006), Iceland (Young 2015), Argentina (Bellazzi et al. 2012) and South Korea (International Whaling Commission 2015).

A general description of mussel longline culture infrastructure and configuration will help understand and visualize how marine organisms may perceive and interact with mussel aquaculture infrastructure in the ocean. The floating raft systems commonly used for culture in nearshore areas are unstable in the open ocean and not likely to be used. Instead, fully submerged, high-tension longlines are most likely to

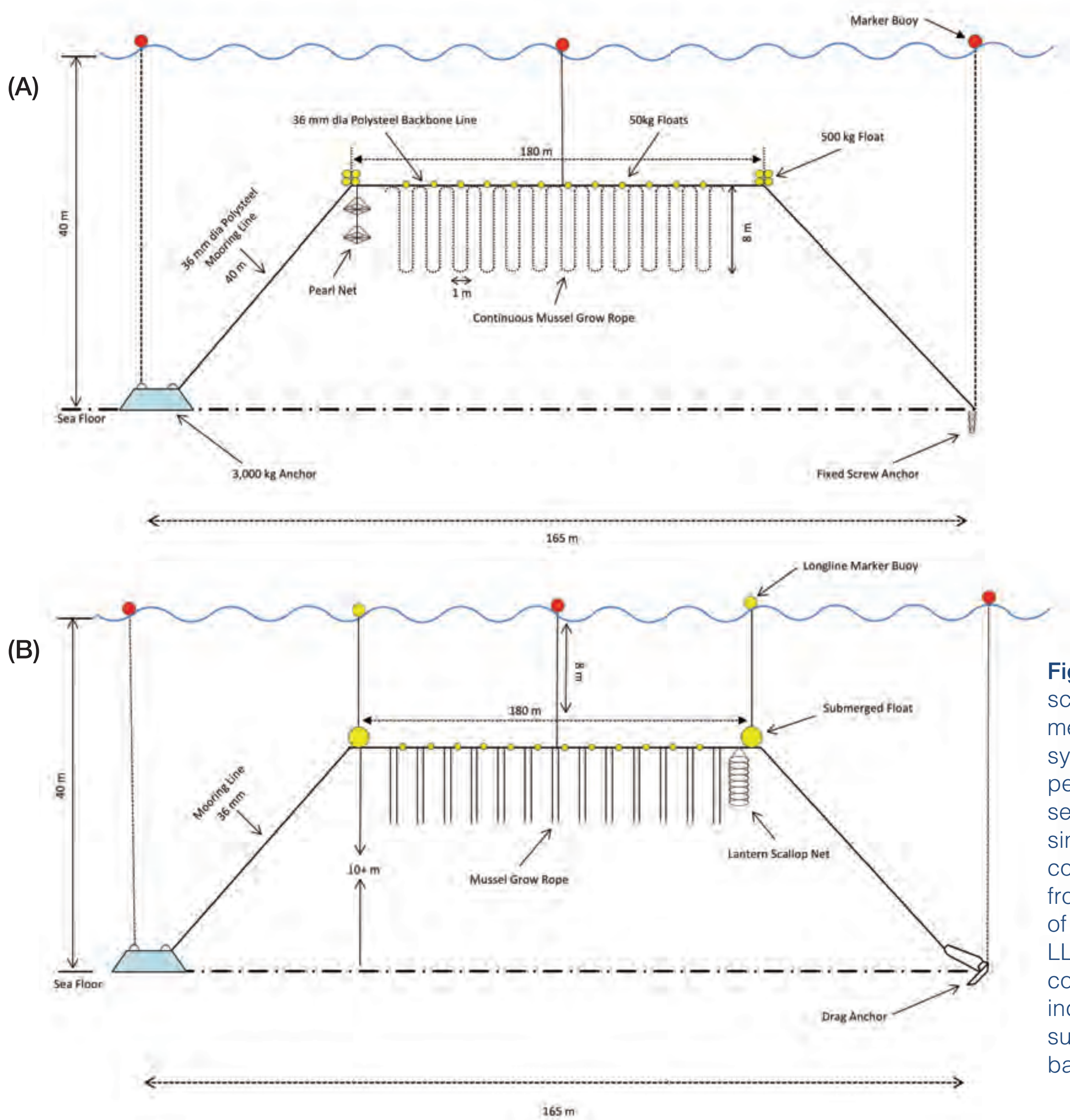


Figure 2. Representative schematics of submerged offshore longline systems used for suspension culture of mussels. View (A) shows a single looped grow rope configuration (adapted from Vincent Prien, Isles of Shoals Mariculture, LLC, Rye, NH, pers. comm.). View (B) shows individual grow out socks suspended from the backbone (Lindell 2014).

be deployed in the open ocean and in high energy nearshore environments (Langan et al. 2010). Figure 2 shows typical specifications for single longlines. Other illustrations of longline gear may be found at the Catalina Sea Ranch website (Catalina Sea Ranch 2015).

At a typical commercial farm, multiple backbone lines are arrayed in parallel rows submerged several meters (5–20m) below the surface using a system of anchors and buoys. The longlines may be 150–300m in length. Submerged floats keep the vertical lines running up from the anchors (Figure 2) and the horizontal longlines properly oriented in the water column and prevent the lines from becoming entangled with each other. Arrays of these longlines are deployed at a farm site spaced 10–20m apart. In many parts of the world, a single farm may include several hundred longlines covering hundreds of acres. Currently in the United States, farms are typically being permitted at smaller scales (less than 100 acres), though it is anticipated that scaling up will follow once the domestic industry expands in the near future.

Each longline is suspended in the water column by two submerged corner floats. These corner floats, in combination with the anchors and the overall geometry of the

GABRIEL BARATHIEU

Mother and calf sperm whale

longline, impart tension to the longline. The longline arrays are suspended in the water column from vertical lines, which are anchored to the seafloor using deadweight anchors, screw anchors, or hydraulic expansion anchors (Ögmundarson et al. 2011). Anchor lines and longlines may be made of materials such as Polysteel with diameters around 36mm. The mussels are grown on separate lines (droppers) suspended individually (Figure 2A) or as a single long looped line (Figure 2B) vertically in the water column from the longlines and seeded with spat. Mussels may be grown out on single droppers (up to about 5m long) or set out in socks. The socks are grow out ropes seeded with spat and secured within a biodegradable (often cotton) sock-like tubing. The grow out ropes or socks are 60 to 100mm in diameter depending on the starting size of the seed, and grow to about 200 to 300mm in diameter at harvest, and are between 3m and 10m long. As the mussels grow, submerged floats are added along the longline to compensate for their weight and to maintain the geometry of the longline. At harvest, the headlines and grow out ropes are pulled up, and the mussels are removed mechanically.

Radar reflecting surface buoys are deployed at the end of each line to alert vessels. The longlines are deep enough (5–20m) to avoid interaction with navigation. Some of the lines, such as the vertical marker buoy lines, can be fitted with breakaway links or weak links designed to break at specified load. It is unknown how commonly this technology is being used at operational commercial farms. Offshore mussel farms are sited in deep water (up to around 50m), so there are many meters of clearance between the bottoms of the mussel grow lines and the seafloor. Nearshore farms, which may be in shallower waters, may have less bottom clearance, which would have to be considered when reviewing permit applications. To assist in these decisions, our review includes information from shellfish and finfish farms located in a variety of depths and distances from shore.

The site specific features of the farm infrastructure that pose potential risk for entanglement and injury are how the high tension anchor lines, the horizontal backbone longlines, the vertically hanging, mussel-embedded grow lines or the surface buoy marker lines are deployed. Generally, it is the slacker grow out lines, spat collecting lines and surface marker buoy lines that cause the most concern (Moore & Wieting 1999, Lloyd 2003, Keeley et al. 2009, Clement 2013).

Aquaculture industry technology has developed in the last decade to produce gear to withstand conditions in the open ocean. It is not possible to present exact specifications for all gear types in this assessment. A range of lines, netting, moorings, anchor systems, and farm configurations are used at shellfish and finfish farms, depending on the species being cultured, site characteristics and scale of the operation (Belle & Nash 2008, Langan 2012, Lekang 2013). Gear specifications and technical details can be expected to be included in individual permit applications.

IT IS LARGELY UNKNOWN HOW MARINE ANIMALS PERCEIVE MAN-MADE STRUCTURES IN THE WATER AND WHAT THEIR ABILITY IS TO RESPOND TO OR AVOID THEM.

It is largely unknown how marine animals perceive man-made structures in the water and what their ability is to respond to or avoid them. That said, it is generally thought that echolocating marine mammals (toothed whales, dolphins and porpoises) can effectively perceive mussel and fish farms and, in most cases, navigate through or around them (Lloyd 2003, Markowitz et al. 2004). However, species of baleen whales are not evolved to echolocate and rely on visual and audio queues, which may put them at higher risk of entanglement (Lloyd 2003). For example, North Atlantic right whales are baleen whales and one of the most endangered species in U. S. waters (Marine Mammal Commision 2008) with a population size less than 500 individuals. Even a few mortalities have the potential to greatly affect the population structure and, potentially, the recovery and persistence of that species in the region (Fujiwara & Caswell 2001). Ship collisions and fishing gear entanglement are known threats to this species in the north Atlantic (NOAA 2015c, Waring et al. 2012, 2015, van der Hoop et al. 2013). A similar concern was raised for southern right whales around the New Zealand mainland where even low mortality rates could impact the viability of the small population (Lloyd 2003, Clement 2013).

Marine Mammals

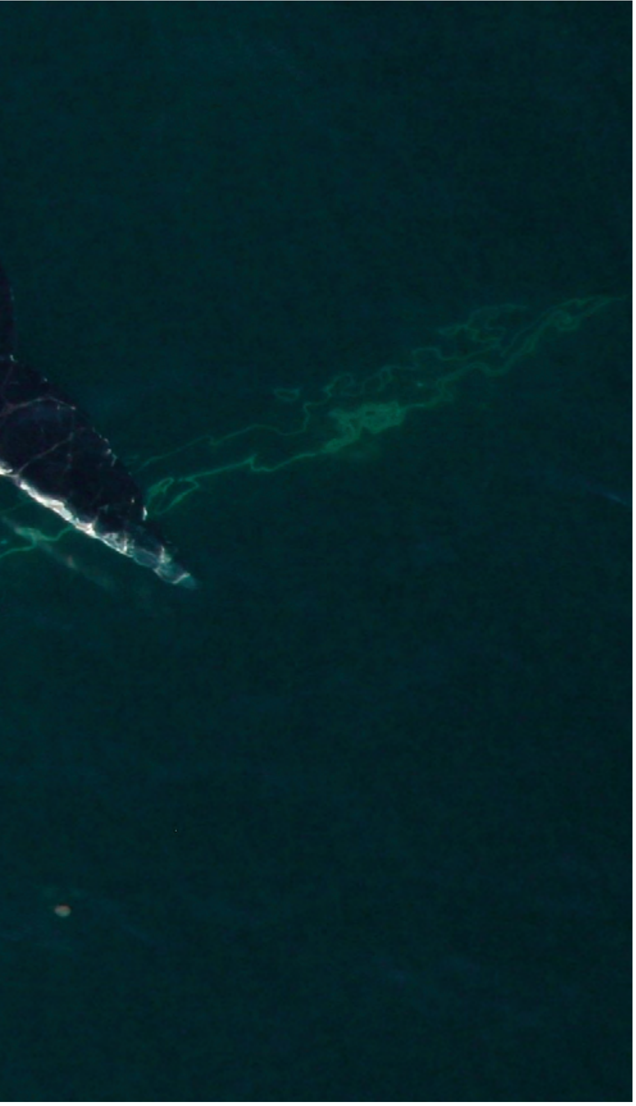
Marine mammals that can potentially encounter an offshore shellfish or fish farm include the pinnipeds (walrus, seals and sea lions), cetaceans (whales, dolphins and porpoises) and the sirenians (manatees and dugongs), all of which occur in U. S. waters. In total, 69 marine mammal species are protected under jurisdiction by NMFS and five by USFWS under the MMPA and ESA (NOAA 2015b). Six ESA-listed marine mammals are found in the Greater Atlantic Region. These include the blue, fin, humpback, north Atlantic right, sei, and sperm whales (Table 1).

North Atlantic right whale with entangling fishery gear

Over a decade ago, Lloyd (2003) identified entanglement, habitat exclusion, marine debris and behavioral alterations as potential risks from mussel aquaculture. Review of the NMFS U. S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments (Waring et al. 2012, 2015) finds very few verified instances of marine mammals being injured by or entangled in aquaculture gear. Most injuries attributable to human interactions involve ship strikes or entanglement in fishing gear. The similarities and differences between aquaculture and fishing gear are discussed later in this assessment. Some gear, such as nautical rope cannot always be attributed to a particular ocean industry or activity. There are aquaculture supply companies providing gear uniquely manufactured to allow the materials to be tracked back to specific farms (Tassal Group Ltd. 2011), but this is not a standard practice.

Effects of Longline Mussel Aquaculture on Marine Mammals

Pinnipeds do not commonly feed on shellfish, so may be less likely to visit offshore shellfish farms (Nash et al. 2000, Würsig & Gailey 2002). Because there are no reported interactions with those species the focus here is on whales and dolphins. Much of the available information about interactions between shellfish farms and marine mammals comes from New Zealand where it is that country's largest aquaculture



GABRIEL BARATHIEU

Longline mussel farm

activity (Keeley et al. 2009) with over 1100 currently active shellfish farms on leases covering 22,000 ha (National Aquatic Biodiversity Information System 2015). One of the concerns facing the industry is the impacts — real and potential — to protected species including marine mammals and seabirds.

In 2013, the government of New Zealand issued a comprehensive summary report on the effects of aquaculture on marine mammals (Clement 2013). The report includes separate analyses of farming of feed-added species (fish) and filter feeders (shellfish). Clement (2013) summarizes the effects of aquaculture to marine mammals and identifies three key areas of potential interactions — competition for space, entanglement, and underwater noise disturbance (Tables 4–7). Impact of alterations in trophic pathways was identified as a fourth area of concern, but a table was not included for that area. These interactions of concern are similar to the potential impacts identified in the Lloyd (2003) assessment.

The potential harmful effects of aquaculture on marine mammals for habitat modifications (Table 4) is not currently considered a high risk, as there is little overlap in critical habitat and farm locations in New Zealand. There is awareness that industry growth, both as an increase in the number of farms as well as expansion into the open ocean, may increase the potential for both habitat exclusion and physical interaction. Management strategies to avoid impacts are done on a case-by-case basis primarily by siting in areas which minimize the likelihood of overlap with migration routes or critical habitats. This may not always be possible in the United States. For example, in New England, farms are being proposed in areas within whale and sea turtle feeding grounds. The extent of possible overlap with protected species in that region is unknown and depends upon which species are being considered and the scale of the proposed project.

Several studies in Admiralty Bay, New Zealand have focused on potential habitat exclusion of dolphins in nearshore waters. There is evidence that dolphins may be

Table 4 Effects of Shellfish Aquaculture on Protected Species Habitat Use (adapted from Clement 2013)

Effects	*Scale*	*Management Options*
May exclude or modify how marine mammals use critical or sensitive habitats. The nature of the exclusion depends on the type of culture method and the particular marine mammal species in the cultivation area.	*SPATIAL* *Local to regional scale* Avoidance may be only from the farm area itself but most likely will involve a bay or region,depending on species and population dynamics.	Site selection to minimize or avoid the likelihood of spatial overlap with species' home ranges, critical breeding and foraging habitats and/or migration routes.
Whales and particular dolphin species tend to be more sensitive to such disturbances, while pinnipeds and other dolphin species (such as common and bottlenose dolphins) may actually be attracted to the novel structures and/or habitat.	*TEMPORAL* *Short to long term* Exclusion may be temporary for migrating species or until resident species habituate to the structure and/or activities or avoidance may be for the farms' duration to permanent.	Continuous monitoring of presence (and absence) of marine mammal species in the vicinity or general region of the farm site is recommended. Monitoring could also include detailed observations of time spent under or around the farm structure, which may later be compiled and analyzed by experts.

Fish farm in fjord near La Junta, Chile

fully or partially excluded from areas nearshore where mussel farms are located. Markowitz et al. (2004) found that during five years of observations, dusky dolphin *Lagenorhynchus obscurus* groups entered mussel farms located <200m from shore, in a bay with many mussel farms, in only 8 of 621 observations. The dolphins were able to navigate through the lanes between the mussel lines, but they selectively avoided farm areas in comparison to unfarmed areas of the larger bay. Duprey (2007) reported similar findings in the same area. In Duprey's study, only 2 of the 332 groups of dusky dolphins observed were seen inside a mussel farm. Of the nine groups of bottlenose dolphins seen, none entered farms. Both studies conclude that expansion of farming in the bay could limit dolphin access to important natural foraging areas.

A study of dusky dolphin behavior (Pearson 2009) similarly found dusky dolphins did not enter farms, but did increase foraging behavior adjacent to the farms, perhaps as a result of forage fishes being attracted to the farm structures. Dolphin traveling (slowed down) and grouping behavior (increased group fusion) were also affected by mussel farms. Watson-Capps and Mann (2005) found that bottlenose dolphins in Shark Bay, Australia decreased their use of shallow areas in a bay once pearl farming with structures similar to mussel farms began, and moved around, rather than through, the farm. These studies were all conducted at nearshore farms (within a few km) in shallow water and no studies have been conducted for similar habitat impacts from offshore longline culture. However, if longline operations rely on nearshore farms for spat collection for seed, these findings become relevant.

In New Zealand, entanglement is considered low risk to marine mammals if best management practices such as the options listed in Table 5 are followed. Lloyd (2003)

A STUDY OF DUSKY DOLPHIN BEHAVIOR SIMILARLY FOUND DUSKY DOLPHINS DID NOT ENTER FARMS, BUT INCREASED FORAGING BEHAVIOR ADJACENT TO THE FARMS, PERHAPS AS A RESULT OF FORAGE FISHES BEING ATTRACTED TO THE FARM STRUCTURES

Table 5 Entanglement risk of farming filter-feeders (adapted from Clement 2013)

Effects	*Scale*	*Management Options*
Physical interactions between aquaculture and marine mammals can lead to an increase risk of entanglement in structures or non-biological wastes from farm production The risk of entanglement increases as predators tend to be attracted to associated aggregations of wild fish	*SPATIAL* *Local to regional scale* Impact occurs at site but may have larger scale consequences at the population level, depending on the species status and population range *TEMPORAL* *Short to long term* Minor injury to individuals to death of critically endangered animals that can have long-term consequences for vulnerable populations	Site selection to minimize or avoid the likelihood of spatial overlap with species' home ranges, critical breeding and foraging habitats and/or migration routes Continuous monitoring of presence (and absence) of marine mammal species in the vicinity or general region of the farm site, detailed observations of any time spent under or around the farm structure, compiled and analyzed by experts. Strict guidelines and standards in relation to potential entanglement risks on the farm including loose ropes, lines, buoys or floats. Provision for disposal and/or processing of non-biological wastes to minimize the risk of attraction and entanglement.

reported two instances of Bryde's whales *Balaenoptera edeni* becoming entangled in spat collection lines and dying as a result. Though the veracity of one of these reports is disputed (Clement 2013), the potential for such mortality is not. Further, no additional incidents of dolphin, pinniped or seabird deaths due to entanglement were reported. Similarly, Baker et al. (2010) report that from 1989 to 2008 two Bryde's whales died from entanglement in mussel spat lines in New Zealand's Hauraki Gulf, likely the same animals included in the Lloyd (2003) report. Clement (2013) was able to find three cases of whales being entangled in shellfish farms—the two Bryde's whales already noted and one humpback calf in Western Australia which was cut free from a crop line after catching it in its mouth and then rolling. The humpback calf may be the same whale reported by Groom and Coughran (2012) as being entangled in mussel aquaculture gear. Clement (2013) also states there are still no confirmed mortalities of pinnipeds or dolphins due to entanglement in mussel lines. Clement suggests that if farm lines are kept tensioned, no loose ropes are left trailing in the water, and farms are located outside of historical migratory paths, the risk of entanglement is likely to be low.

Table 6 Underwater noise caused by farming of filter-feeders (adapted from Clement 2013)

Effects	*Scale*	*Management Options*
Underwater noise is associated with regular, ongoing farm activities (including vessels) may either exclude or attract marine mammals Whales and particular dolphin species tend to be more sensitive to such disturbances, while pinnipeds and other dolphin species (such as common and bottlenose dolphins) may actually be attracted to the novel noise source	*SPATIAL* *Local to regional scale* Impact occurs at the site but the scale is dependent on the recurrence and intensity of sounds generated and the hearing and/or vocalizing range of the mammal species *TEMPORAL* *Short to long term* Dependent on the recurrence and intensity of sounds generated and the hearing and/or vocalizing range of species	Site selection to minimize or avoid the likelihood of spatial overlap with range restricted species' home ranges, critical breeding and foraging habitats and/or migration routes Monitoring of presence (and absence) of marine mammal species in the vicinity or general region of the farm site, detailed observations of any time spent under or around the farm structure, compiled and analyzed by experts Monitor and regularly review on-farm management and maintenance practices to minimize the risk of underwater noise pollution

Issues regarding risk from underwater noise at farms, and management options to address those risks are summarized in Table 6. No studies in New Zealand or elsewhere have directly studied the effects of daily activity farm noise on marine mammals. However, extensive work (discussed later in this assessment) is underway to use acoustic deterrent devices (ADDs) to prevent predatory marine mammals from entering fish farms. Clement (2013) concludes there is low risk to protected species from mussel culture, at both offshore grow out operations and spat collection sites. These findings are consistent with those in earlier reports on the wider environmental impacts of the industry (Kemper et al. 2003, Baker 2005, Keeley et al. 2009). Clement (2013) concludes that currently habitat exclusion is considered a minor issue for marine mammals and that as long as mussel farming expansion does not overlap with breeding, migrating and feeding habitats of protected species, few negative interactions are expected. In addition to habitat exclusion, consideration should be given to the potential for marine mammals to be displaced to sub-optimal or unfavorable habitats if they alter movement patterns to avoid interactions with farms.

In addition to the interactions summarized above, primarily from New Zealand, there are a few reports from other countries regarding entangled protected species (Table 8). In a report on right whale entanglements in Argentina from 2001–2011 there is a report of a single right whale entanglement in 2011 which may have

Green sea turtle swimming along a vertical reef

Table 7 Overview of potential marine mammal interactions with shellfish farming (adapted from Clement 2013)

Effects	*Management Options*
Habitat exclusion or modification leading to less use or less productive use	Careful site selection and consideration of area covered.
Potential for entanglement	Regular maintenance of farm structures, including keeping lines secured and anchor warps under tension
Underwater noise disturbance	
	Ensure waste material and debris is collected and disposed of correctly
	Monitoring of presence of marine mammal species in vicinity of farm

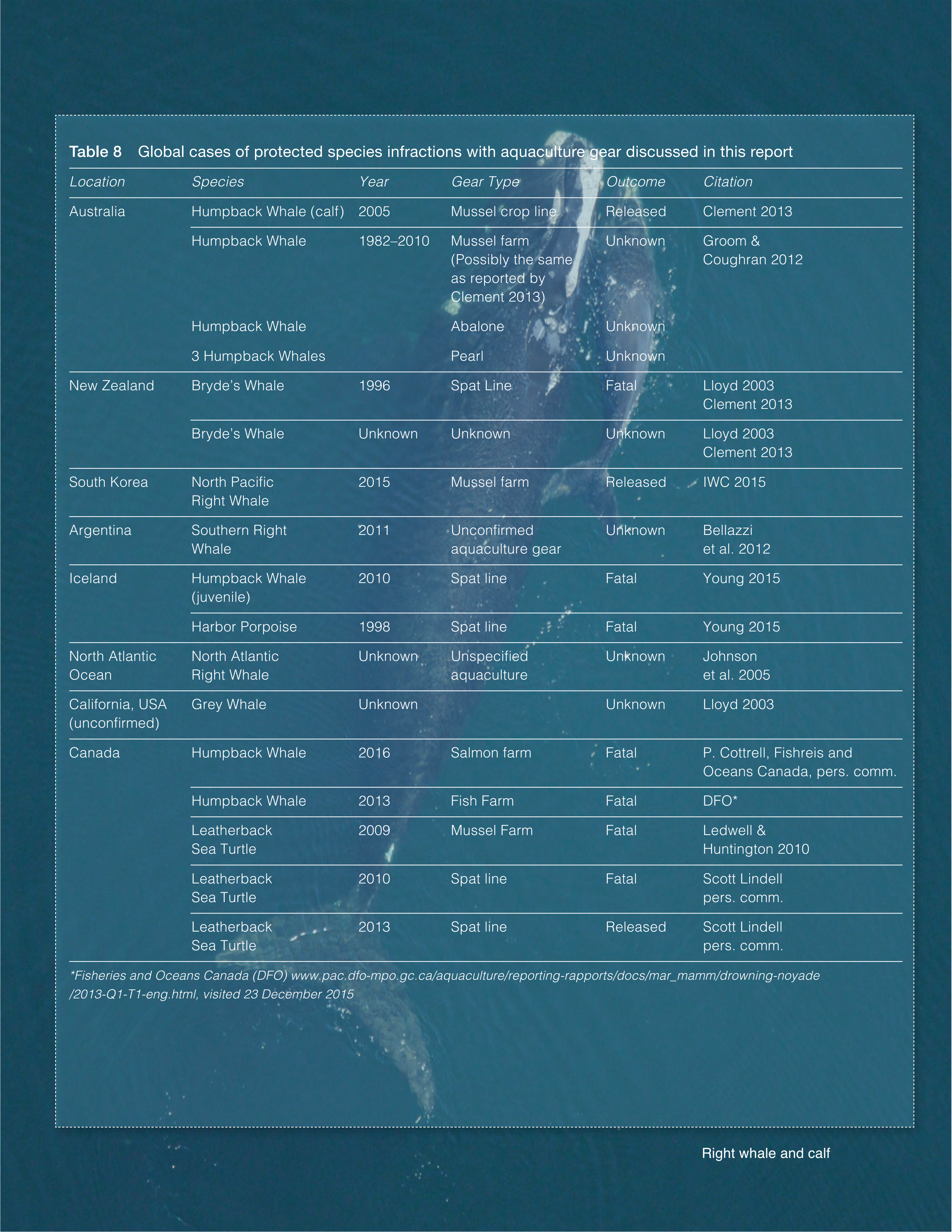
involved mussel spat collection lines, but this was not confirmed (Bellazzi et al. 2012). There are reports of two fatal marine mammal entanglements in mussel farms in Iceland (Young 2015), a harbor porpoise *Phocoena phocoena* in 1998 and a juvenile humpback whale in 2010. Single dropper spat collection lines were involved in both incidents. In February 2015, a young North Pacific right whale was entangled in ropes in mussel aquaculture gear off Korea (International Whaling Committee 2015). The whale escaped after volunteer responders assisted in cutting anchor lines wrapped around the caudal peduncle.

Research has been conducted in other countries to evaluate how marine mammals may be affected by nearshore mussel farms. In Yaldad Bay in southern Chile, Heinrich (2006) reported that Chilean *Cephalorhynchus eutropia* and Peale's *Lagenorhynchus australis* dolphins observed in extensively farmed areas (shellfish and finfish) avoided direct interaction with farms. Peale's dolphins were never observed closer than 100m to farms. Chilean dolphins fed on schooling fish adjacent to farms and in open spaces between dense sets of grow lines. Seven animals were seen crossing under shellfish lines and floats, but the clearance between the lines and seafloor was unknown. The potential for habitat exclusion of these dolphins was considered to be likely in areas with high levels of mussel farms. In the same region, (Ribeiro et al. 2007) reported that Chilean dolphins used areas with less than 30% coverage of mussel farming, but were absent from areas with greater than 60% coverage. As in other studies, foraging behavior was observed near the mussel lines, possibly on fish attracted to the structures. In this region, habitat exclusion due to high density of aquaculture (32% of the area contains mussel farms) was considered a concern because it restricted use of essential habitat.

Table 8 Global cases of protected species infractions with aquaculture gear discussed in this report

Location	*Species*	*Year*	*Gear Type*	*Outcome*	*Citation*
Australia	Humpback Whale (calf)	2005	Mussel crop line	Released	Clement 2013
	Humpback Whale	1982–2010	Mussel farm (Possibly the same as reported by Clement 2013)	Unknown	Groom & Coughran 2012
	Humpback Whale		Abalone	Unknown	
	3 Humpback Whales		Pearl	Unknown	
New Zealand	Bryde's Whale	1996	Spat Line	Fatal	Lloyd 2003 Clement 2013
	Bryde's Whale	Unknown	Unknown	Unknown	Lloyd 2003 Clement 2013
South Korea	North Pacific Right Whale	2015	Mussel farm	Released	IWC 2015
Argentina	Southern Right Whale	2011	Unconfirmed aquaculture gear	Unknown	Bellazzi et al. 2012
Iceland	Humpback Whale (juvenile)	2010	Spat line	Fatal	Young 2015
	Harbor Porpoise	1998	Spat line	Fatal	Young 2015
North Atlantic Ocean	North Atlantic Right Whale	Unknown	Unspecified aquaculture	Unknown	Johnson et al. 2005
California, USA (unconfirmed)	Grey Whale	Unknown		Unknown	Lloyd 2003
Canada	Humpback Whale	2016	Salmon farm	Fatal	P. Cottrell, Fishreis and Oceans Canada, pers. comm.
	Humpback Whale	2013	Fish Farm	Fatal	DFO*
	Leatherback Sea Turtle	2009	Mussel Farm	Fatal	Ledwell & Huntington 2010
	Leatherback Sea Turtle	2010	Spat line	Fatal	Scott Lindell pers. comm.
	Leatherback Sea Turtle	2013	Spat line	Released	Scott Lindell pers. comm.

**Fisheries and Oceans Canada (DFO) www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/docs/mar_mamm/drowning-noyade /2013-Q1-T1-eng.html, visited 23 December 2015*



Right whale and calf

Peale's dolphins

In Europe, shellfish production is extensive, but there are few studies which addressed impacts to protected species (McCormack et al. 2009). Roycroft et al. (2004) assessed impacts of mussel culture in Bantry Bay on the southwest coast of Ireland on harbor seal numbers. The project was conducted at nearshore mussel farms sited in sheltered deep (up to 20m) water using floating longlines to suspend 15m vertical grow lines in the water column. Seal abundance was the same at sites with and without mussel farms, and no negative interactions were reported. It was hypothesized that because seals and other pinnipeds may carry parasites, they could pose some risk for transferring parasites (nematodes and lice) between adjacent farms.

No studies have been conducted in the United States to directly investigate impacts to marine mammals from open ocean mussel aquaculture. However, there are also no reported (either in the scientific literature or in public media) incidents of harmful interactions with commercial or experimental farms that have operated in U. S. waters. Nash et al. (2000) suggested that negative interactions with pinnipeds are likely to be reduced at mussel farms because shellfish are not a common food source for them. A habitat use study of odontocete cetaceans around Hawaii concluded that it may be difficult to find locations for marine aquaculture that do not overlap with any protected species (Baird et al. 2013). Johnson et al. (2005) reported that of 20 North Atlantic right whales entanglement reports on file with NMFS dating back to 1993, one was reported entangled in aquaculture gear, but no further details were provided.

In summary, the above studies suggest interactions and entanglements with longline mussel aquaculture gear worldwide are rare and close approaches by protected species are seldom documented. Entanglement risk for cetaceans depends on several species-specific factors. Inquisitive or playful individuals will be more at risk. Species or individuals that roll when encountering entangling gear may be more likely to become severely wrapped (Weinrich 1999). Additionally, entanglements occurring below the surface will be difficult to detect. Species that do not echolocate may not perceive three dimensional farm structures as well as species that do. In general, larger, less agile species with flippers and fins that extend relatively far from the body (Keeley et al. 2009) and gaping mouths (see Cassoff et al. 2011 for a description of how gaping mouths may make some whales more prone to oral entanglement) may be more likely to have negative physical interactions. It is largely unknown how marine animals perceive man-made structures in the ocean, and therefore using visual, auditory, or other sensory cues to elicit an aversion behavior often involves tentative investigation (Tim Werner, New England Aquarium, pers. comm.). Because pinnipeds do not commonly feed on shellfish, they may be less likely to visit farms (Nash et al. 2000, Würsig & Gailey 2002). Though there is concern about potential indirect ecosystem effects that may affect marine mammals, there is currently little or no research in that area. Table 7 summarizes the findings and recommended management options from New Zealand which may be useful in developing management strategies for U. S. facilities.

PHYSICAL BARRIERS, INCLUDING RIGID NETTING AROUND CAGES, ARE THE BEST MANAGEMENT OPTIONS TO DECREASE HARM, ALONG WITH SITING OF CAGES OFFSHORE FAR AWAY FROM HAUL OUT SITES AND ROOKERIES.

Marine Mammal Interactions With Other Aquaculture

Marine mammal interactions with marine finfish aquaculture was recently reviewed and summarized by Price & Morris (2013). Marine aquaculture operations may displace marine mammals from their foraging habitats (Markowitz et al. 2004, Cañadas and Hammond 2008) or cause other disruptions to their behavior (Early 2001). Entanglement in nets or lines around fish farms may cause injury, stress or death to marine mammals. Kemper et al. (2003) evaluated negative interactions of marine mammals with aquaculture in the southern hemisphere and found that most known interactions occur at finfish farms and involve predatory pinnipeds.

Pinnipeds

Jamieson and Olesiuk (2002) provided a thorough review of pinniped interactions with salmon farms in Canada, describing the financial impacts to the industry, methods for non-lethal intervention and the ecological implications of lethal deterrents to the seal and sea lion populations. Damages to the farm stock or gear may be only a few thousand dollars for an individual farm, but can total millions of dollars for a single

California sea lions

Table 9 Nuisance pinnipeds killed under license in British Columbia from 1990–2010 (DFO 2011)

Year	*Harbor Seal*	*California Sea Lion*	*Steller Sea Lion*
1990	211	0	0
1991	391	3	11
1992	423	3	5
1993	483	14	9
1994	414	3	3
1995	577	24	6
1996	512	57	27
1997	542	59	37
1998	391	92	63
1999	499	147	103
2000	426	243	49
2001	298	92	30
2002	123	20	17
2003	48	14	3
2004	120	6	0
2005	69	9	0
2006	121	3	0
2007	93	7	0
2008	32	5	0
2009	50	22	0
2010	56	170	0

country in a year. The growth of the fish farming industry and concomitant expansion of pinniped populations has tended to increase the number of interactions, but previously used lethal control methods are less viable due to conservation objectives and regulatory protection. Typically, only single individuals may be killed and only after multiple forays into the farm with repeated attempts to deter the animal. They note that the United States has even stricter regulations with respect to lethal removal, and it is not expected that lethal control will be readily allowed in the United States.

Other countries with large marine fish aquaculture sectors allow farms to undertake lethal methods of predator control, and illegal culling is also occurring (Northridge et al. 2013). In Canada, public reports on authorized marine mammal control activities at salmon farms are available on the government's Fisheries and Oceans Canada website (DFO 2011, 2013, 2015). There is a decreasing trend in the number of marine mammals killed in British Columbia salmon farms, despite concurrent increases in both the number of fish farms and seal and sea lion populations (Table 9). The website also provides information about the numbers of accidental marine mammal drownings at fish farms from 2011–2014. These are often animals which become tangled under-

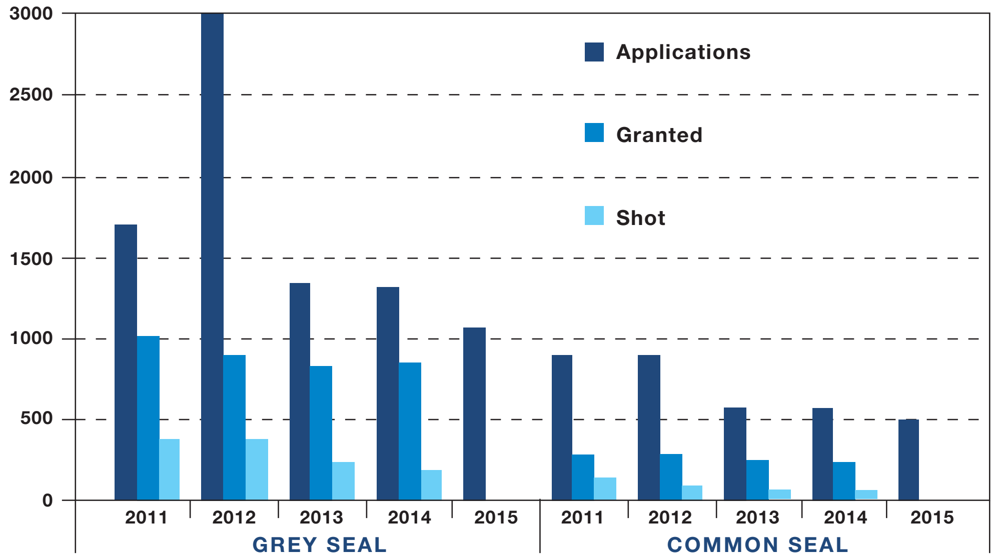


Figure 3. Comparisons of grey and common seal depredation permit applications submitted, applications granted, and numbers of actually shot in Scotland from 2011–2015. Adapted from government data (Scottish Government 09 December 2015).

water in the cage netting or other farm gear. Between 2 and 20 animals—mostly seals and sea lions, but including one humpback whale in 2013—drowned annually.

In Scotland, shooting of seals is also licensed for aquaculture operations and the government posts information about seal depredation licensing on its website (Scottish Government 2015). Data from the website (Figure 3) reflects the declining trend in the number of licenses requested and issued, and the resulting number of animals killed from 2011 to 2015. In 2010, new marine mammal conservation legislation was enacted which reduced the shooting of seals. Prior to 2002, on average 312 seals were shot per year (Department of Energy and Climate Change (UK) 2009).

Würsig and Gailey (2002) reviewed the conflicts between aquaculture and marine mammals and six options for reducing marine mammal impacts are discussed: harassment, aversive condition, exclusion, nonlethal removal, lethal removal and population control. Harassment by chasing, explosives, and ADDs have been found to be only somewhat effective and generally only in the short term until animals become habituated. In fact, it is possible that over time noise harassment devices may actually become attractants to habituated individuals who come to recognize the sound as an unpleasant dinner bell. Predator models and sound devices (imitating killer whales for example) are also not very effective.

HARASSMENT BY CHASING, EXPLOSIVES, AND ADDS HAVE BEEN FOUND TO BE ONLY SOMEWHAT EFFECTIVE AND GENERALLY ONLY IN THE SHORT TERM UNTIL ANIMALS BECOME HABITUATED.

The dangers that these harassment techniques pose toward target and non-target marine life were discussed. Aversive conditioning refers to feeding poisoned (with lithium chloride, for example), but not deadly, bait to sicken the offending animals. This has also proved to be only ephemerally useful. Non-lethal capture and relocation of problematic individual animals is feasible, but very expensive, time-consuming and minimally effective. Relocated animals often return quickly to the farm area. Lethal removal and large scale population control (or culling) are generally not very effective, popular or legal options. Removing problem animals may help in some in-

Harbor seals hauled out on a shellfish farm

stances where an individual is causing damage, but typically more animals will just move in. Large-scale population control methods like culling are highly unlikely to be supported in the United States.

ADDs are a common method used to deter predatory pinnipeds, but their effectiveness is highly variable. In some areas, they seem to offer protection, but in other areas they are completely ineffective. ADDs are designed to cause auditory discomfort to pinnipeds by emitting sound underwater at a range of frequencies. However, as discussed below, these devices have also been shown to deleteriously impact non-target marine mammals.

Terhune et al. (2002) found that ADDs near aquaculture facilities in the Bay of Fundy did not elicit startle responses, measurable avoidance behavior or changes in haul-out behavior in pinnipeds that had been exposed to ADDs for many years. Surveys of salmon farm managers in Scotland (Northridge et al. 2010) found ADDs were not in use at all farms and were not thought to be very effective. The authors indicated that seal predation has declined over the past decade and that less than a quarter of salmon farms reported major problems with seals despite nearly daily sighting of seals near farms. Rogue individuals were thought to cause the most damage and individual recognition techniques are being improved as a potential management tool. Farm management strategies including net tensioning, removing mortalities, lower stocking densities and installing seal blinds at the bottom of the nets deterred predation where reported by the farmers as more effective deterrent measures. In addition to the ADDs, Terhune et al. (2002) reviewed other nonlethal interventions including harassment by boat or with noise (such as underwater seal firecrackers), aversive conditioning, predator (killer whales) models or sounds, and the use of acoustic devices and relocation. Often, harassment techniques are effective in the short term, but may be less efficacious over time as animals become habituated.

KARIN BEATE NØSTERUD

Norwegian salmon farm

A three-month study at Chilean salmon farms reported significantly lower sea lion predation after installation of an ADD compared to a similar farm with no device (Vilata et al. 2010). In 2007, 13.17t of salmon were predated by sea lions from April to June 2007. In contrast, for the same period of 2008, an ADD was used and just 7.75t were predated. This farm also had significantly lower depredation in 2008 compared to a similar nearby farm with no device installed (42.33t). However, at a nearby farm, the same ADD was ineffective. The short span of the study left doubts about the long-term effectiveness. Farm management was recommended as being equally or more protective against predation. The researchers also found interactions of the sea lions followed patterns linked to daily and annual circa-rhythms, the intensity of the tidal flux, and prey size.

Effort has been focused in Scotland on understanding how pinnipeds interact with farms and developing non-lethal control measures to deter them from fish farms and other marine industry sectors. Only about half of Scottish farmers use ADDs, with many relying heavily on farm management and husbandry practices to decrease predation. Underwater video surveys at 13 farms provided extensive and detailed information about individual behavior patterns of seals, how seals access the fish through net holes, effectiveness of predator nets, net management issues that affect predation success, patterns of seal attack on fish, the extent of predation across the industry, timing of predation during the grow out cycle, geographic patterns of predation occurrence and intensity, and review of ADD effectiveness (Northridge et al. 2013). This study also investigated the secondary effects of a previously untested ADD on harbor porpoises which are protected and do not pose a predation threat to salmon farms. There was little evidence of any significantly reduced porpoise activity due to the ADD being turned on, but there was a weak trend indicating decreased activity closest to the ADD. Another part of the study, tested signal characteristics of four different transducers, finding only one was around 120kHz, the same frequency band as harbor porpoise echolocation clicks.

ONLY ABOUT HALF OF SCOTTISH FARMERS USE ADDS, WITH MANY RELYING HEAVILY ON FARM MANAGEMENT AND HUSBANDRY PRACTICES TO DECREASE PREDATION.

Coram et al. (2014) conducted a comprehensive assessment of the design, effectiveness and impacts of the variety of deterrent devices used in aquaculture and other aquatic activities. Great uncertainty remains about just how effective ADDs are,

CSIRO

Australian salmon farm

though evidence from experimental trials and farmer interviews suggest they can sometimes decrease pinniped predation in some areas for at least short durations. Other farm management practices such as net tensioning, adding false bottoms to avoid predation from below, removal of dead fish and antipredator nets may be as, or more, effective. Alternative measures such as electrical fields, conditioned taste aversion, trapping and relocation, and playing predator vocalizations, and sonar are also evaluated. The authors note that more scientific work has focused on the impacts of ADDs to non-target species rather than their efficacy in deterring predators. They point out the historical lack of field research directly addressing effectiveness and impacts to non-target protected species Their report also includes information about the use of deterrents used in capture fisheries, to protect wild stocks, and in other aquatic industries and activities.

Lepper et al. (2014) conducted an in-depth assessment of the damage risk from three ADDs commonly used in Scotland to deter marine mammals including pinniped predators and non-target cetaceans. The assessment combined modeling of sound propagation with sound exposure criteria to determine safe exposure limits and noise influence zones for aquaculture. They combined the sound characteristics with environmental factors such as depth, sediment and seabed slope to model sound propagation loss. The modeling data was then coupled with species-specific injury (hearing loss) thresholds for each device resulting in output curves for each device. The difference in risk between types and numbers of devices deployed in varying environments (sediment, depth, slope) was calculated to determine distance and time thresholds for exposure before injury would be expected. Results of the modeling indicated that there is a credible risk of exceeding injury criteria for both seals and porpoises, and it is possible that ADDs deployed at Scottish aquaculture site can cause permanent hearing damage to marine mammals. The modeling indicated that porpoises were at higher risk than seals for injury.

Other management alternatives provide additional options for reducing interactions with marine mammals. As others, Würsig and Gailey (2002) conclude that exclusion is the most effective measure. Also, siting is noted as being an important tool. For example, farms located distantly (>20km) from haul-out sites tended to have fewer instances of pinnipeds trying to forage on farmed fish (Würsig & Gailey 2002).

Research results support the views and conclusions in the foregoing three review papers (Würsig & Gailey 2002, Coram et al. 2014, Lepper et al. 2014). At 11 out of 25, sea bass and sea bream fish farms surveyed in the Turkish Aegean, individual monk seals were documented taking fish and damaging nets, mostly at nighttime feedings during the winter months (Guecluesoy & Savas 2003). A range of non-lethal deterrents was ineffective and only the installation of anti-predator nets was successful in avoiding fish losses. Aerial and ship surveys conducted in New Brunswick by Jacobs and Terhune (2000) suggested that harbor seals do not congregate in salmon farming areas, nor do the farms seem to disrupt the mammals' normal movement patterns.

In New Zealand, predation by seals and sea lions at fish farms is considered a continuing problem for tuna farmers in Port Lincoln (Goldsworthy et al. 2014). The use of fencing to exclude pinnipeds is largely successful as long as repairs to holes are quickly mended and fish carcasses are removed frequently. The smaller seals reportedly jumped over the fences to feed on wild fishes or bait fish fed to the tuna, while sea lions were the greater threat to the tuna. Large seal colonies and haul-outs were located near the tuna farms.

Good success in deterring pinniped predation is achieved using rigid net materials for fish cages or the installation of rigid exclusionary nets around salmon farms. These may be expensive to install, require follow up maintenance and cleaning and, in the case of secondary nets, may decrease water flow through the fish cage. Exclusion nets must be strong enough to resist chewing or tearing. Best management practices to deter predators include siting away from marine mammal aggregations, installing predator nets and other barriers, varying farm routines, using olfactory deterrents and dogs where appropriate (Belle & Nash 2008), and installing electrical fencing around cage perimeters (Rojas & Wadsworth 2007).

One case study in the United States in central California involving shellfish farming may be of interest when considering potential interactions with onshore operations such as spat collection facilities to support offshore operations. In 2013, a U. S. oyster farm operating in the Drakes Estero was declined a lease renewal after more than 40 years of operation. The farm was in the Point Reyes National Seashore (managed by the U. S. National Park Service as a designated wilderness area) and adjacent to important habitat for Pacific harbor seals *Phoca vitulina richardsi.* Two National Park Service studies (Becker et al. 2009, 2011) and a summary report by the Marine Mammal Commission (2011) suggested there may be some correlation between the oyster mariculture activities (e.g., vessels operated near haul-outs) on the

ENVIROMET

ENVIROMET

Top: Copper alloy mesh installed at a salmon farm in Tasmania. Bottom: Copper alloy net deployed at a salmon farm in Chile

GOOD SUCCESS IN DETERRING PINNIPED PREDATION IS ACHIEVED USING RIGID NET MATERIALS FOR FISH CAGES OR THE INSTALLATION OF RIGID EXCLUSIONARY NETS AROUND SALMON FARMS.

Bluefin Tuna net pen being pulled through the Mediterranean Sea.

habitat use patterns of the seals. The NMFS disagreed and is on record as indicating that the oyster farm activities had no significant effect on seals (NMFS 2011). Ultimately, although there was significant disagreement about the strength of any causal relationship and the credibility of the data (Frost 2011), the federal lease renewal was denied by the U. S. Department of the Interior, and the farm was ordered to stop operations on the grounds that the lease had expired.

Other Marine Mammals

Dolphins have been documented feeding on wild fish attracted to marine fish farms off Italy, but were not reported to predate caged fish (Diaz López et al. 2005). In a recent five-year study at Italian sea bass *Sparus auratus*, sea bream *Dicentrarchus labrax* and meagre *Argyrosomus regius* cages, Diaz López (2012) observed individually identified dolphins to assess patterns of habitat use and farm fidelity. Dolphin occurrence near the farm varied with time of day, season and year. Individual animals fell within four farm fidelity categories: farmers (occurrence rates > 50%; 20% of individuals), frequent (occurrence rates 25–49%; 10% of individuals), occasional (seasonal occurrence rates < 25%; yearly occurrence > 25%; 20% of individuals) or sporadic visitors (occurrence rates < 25%; 50% of individuals). Dolphins near farms were typically foraging on wild fish concentrated in the farm, but also fed on discarded or escaping fish during harvesting operations. Annual dolphin mortality was 1.5 per year and five animals were found entangled in nets during the study period. The potential for marine mammals to become entangled and drown in farm structures or lines is a predominant concern (Würsig & Gailey 2002, Diaz López and Shirai 2007). This risk can be minimized by siting farms in areas away from known migration routes, using rigid net materials or secondary rigid antipredator nets, and keeping mooring lines taut.

Bottlenose dolphin

Common dolphin

An ecosystem modeling approach in the Ionian Sea concluded that increased productivity from fish farm nutrients had positive impacts to bottlenose dolphin populations in the region (Piroddi et al. 2011). The increase of fish farms was the main explanatory variable that was successfully used to reconstruct the observed trends in dolphin biomass and distribution from 1997 to 2008. In oligotrophic waters, rapid transfer of nutrients up the food web has been shown to increase commercial fish biomass, and fish farms are known to act as attracting devices for forage fishes (see review in Price & Morris 2013). A study in central Greece found that bottlenose dolphin occurrence was higher in areas within 5km of fish farms and lower at areas more than 20km from farms (Bonizzoni et al. 2014). Observed dolphins were thought to be foraging, often within 10m or less of the fish cages and did not appear to avoid farm structures or noise from farm activities. Interestingly, not all fish farms held equal appeal. Dense farm aggregations and gentler slope had a higher probability of dolphin occurrence. Interviews with the farm employees revealed dolphins were not considered a threat and ADDs are not used in this area.

In Scotland, detectors were placed at salmon farms and reference sights to monitor porpoise activity and response to ADDs (Northridge et al. 2010). Generally, porpoises avoided farm areas when ADDs were turned on but returned quickly when they were deactivated. Some animals were observed foraging near farms with active ADDs, especially in areas where the devices had been deployed for some time. Concerns are

Salmon farming in the Reloncavi Estuary, Chile

raised about the impacts of the noise pollution caused by ADDs to non-target marine mammals which pose no predation threat. For example, in British Columbia, harbor porpoises avoided areas during times when ADDs were activated (Olesiuk et al. 2002). A study in New Zealand (Stone et al. 2000) found that Hector's dolphins *Cephalorhynchus hectori*, a rare species, avoided acoustic gillnet pingers, suggesting that use of similar devices at salmon farms to deter pinnipeds could also impact non-target mammals. Early (2001) noted that killer whales *Orcinus orca* in British Columbia avoided marine farm areas where ADDs are in use. This is confirmed by another study in the Broughton Archipelago where killer whales avoided marine areas near salmon farms with ADDs installed to deter pinnipeds (Morton 2002). Following removal of the devices six years after deployment, the whale numbers rose to levels similar to previous levels. Killer whale numbers in a nearby farm area without ADDs remained stable during this same time period. To date, there are no available reports on the impacts of marine fish cage culture to manatees and dugongs, yet potential impacts to these animals should be considered at sites within their habitat range (Würsig & Gailey 2002).

A recent marine mammal habitat use and abundance survey in Hawaii identified aquaculture as a human activity that requires knowledge of marine mammal distribution to inform environmental planning in the coastal zone (Baird et al. 2013). This study identified strong species specific depth preferences that can be useful for

Fish farms near Kalymnos, Greece

assessing overlap with activities or structures in fixed locations such as aquaculture. For example, bottlenose and spinner *Stenella longirostris* dolphins were found mostly in shallow waters (500m), short-finned pilot whales *Globicephala macrorhynchus* in moderate depths (1000–2000m) and Risso's dolphins *Grampus griseus* in very deep waters (3500–5000m).

Currently, there are no published data on interactions of marine mammals with finfish aquaculture in the United States. There is a single account by Lloyd (2003) of a gray whale *Eschrichtius robustus* entangled in aquaculture gear off California sometime prior to 2000. This account is cited by Lloyd as a personal communication by Elizabeth Slooten with a person of the last name Stack. This account has not been verified, and the incident is not reported in the 1997, 2000 or 2002 NMFS gray whale stock assessment reports (NOAA 2015a). Recently (September 2016), a juvenile humpback whale was discovered wrapped through the mouth of a single anchor line at a site which contained mooring buoys from a formerly active salmon farm near Klemtu, British Columbia, Canada. No net pens or other aquaculture structures were present at the site, only mooring buoys. The animal was released after several hours of work by trained rescuers. A few months later (November 2016), an additional humpback whale was entangled at the same location in an adjacent mooring buoy anchor tag line resulting in a fatality due to line wrapping around the whale's tail stock. A third entanglement was reported in November 2016 by Canadian officials at a second location in Nootka, British Colombia, Canada when an 11.5 m female humpback breached the predator net of a salmon farm from underneath in deep water and drowned in the pen (P. Cottrell, Fisheries and Oceans Canada, pers. comm.).

Marine mammal siting and activity records collected by farm workers at a commercial U. S. farm from 2010 to the present (over 550 observations) included no observations of harmful interactions such as entanglement, injury or mortality (J. Lowell, pers. comm.), despite being located less than one mile offshore in a whale national marine sanctuary. Dolphins, whales and pinnipeds were frequently observed near the farm and in proximity to the cages. Some individuals with distinguishing features were seen

IN ACCORDANCE WITH THE REGULATIONS IN THE MARINE MAMMAL PROTECTION ACT, FARM WORKERS SHOULD BE DIRECTED TO AVOID INTERACTING WITH PROTECTED SPECIES, AND TRAINED NOT TO FEED PROTECTED SPECIES.

repeatedly, but did not take up permanent residency. Dolphins that lingered at the farm site were reported to forage, play, mate, follow boats, and approach divers and cages.

In accordance with the regulations in the Marine Mammal Protection Act, farm workers should be directed to avoid interacting with protected species, and trained not to feed protected species. It is known that one U. S. marine farm had workers that were feeding dolphins, but this practice was halted immediately once it was reported (Alan Everson, retired, NOAA, Pacific islands Regional Office, pers. comm.).

Sea Turtles

All sea turtles in U. S. waters are listed under the ESA as threatened or endangered. The five species of sea turtles found in the U. S. Atlantic Ocean are green, hawksbill (rare visitor to the northeast), Kemp's ridley, leatherback, and loggerhead sea turtles. Juveniles, and to a lesser extent, adults are commonly found in the Greater Atlantic Region.

Longline Mussel Aquaculture Interactions

There are three known incidents involving leatherback sea turtles being entangled in mussel ropes in Notre Dame Bay, Newfoundland. In 2009, a turtle was found dead and rolled up in mussel farm lines (Ledwell & Huntington 2010). Two individuals have been reported entangled in spat collection lines. In 2010, one leatherback sea turtle was found dead at depth, while in 2013 the second was found alive at the surface and released after being disentangled around the head and flippers (Scott Lindell, Marine Biological Laboratory, pers. comm.).

Green sea turtle

Other Aquaculture Interactions

One leatherback was documented entangled in shellfish aquaculture gear in the Greater Atlantic Region. This animal was entangled in the vertical line associated with the anchoring system (Kate Sampson, NOAA, GARFO, pers. comm). Like seabirds, sea turtles are generally perceived as incidental visitors at sea cages and not as predatory threats (Nash et al. 2005, Helsley 2007). Because these animals are protected in the United States and elsewhere as threatened or endangered species, potential impacts to sea turtles are an environmental concern associated with marine cage culture (Bridger & Neal 2004, Huntington et al. 2006, IUCN 2007, Borg et al. 2011). Yet, relatively little is known about how sea turtles may be impacted by such facilities. The primary concern with respect to these animals and marine cage culture tends to be the threat to the animals of entanglement with nets, lines or other floating equipment. Management recommendations to reduce negative interactions include the use of rigid netting material for the cage, keeping mooring lines taut and removing

DAVID RABON

Leatherback sea turtle

any loose lines or floating equipment around the farm (Clement 2013, Price & Beck-Stimpert 2014). Lines made of stiff materials are proposed to help prevent entanglement (Price & Morris 2013), but specific guidelines for tensioning of lines are lacking. Additionally, the proper disposal of all trash will reduce the risk that sea turtles will ingest plastic or other trash associated with farm operations. A study investigating hearing capabilities in sea turtles indicates they hear best at frequencies <1,000 Hz (Piniak et al. 2012), which is outside the range typically used for marine mammal ADDs.

Seabirds

Longline Mussel Aquaculture Interactions

Seabird entanglement at mussel farms is a concern (Roycroft et al. 2007a, Keeley et al. 2009), though few studies reporting injury or mortality rates are available. A study in southwest Ireland (Roycroft et al. 2004) found no adverse effects on the abundance or species richness of seabirds at nearshore mussel farms (depth was 14–17m).

There were more birds present in mussel farm areas, especially cormorants and gulls. The authors suggest birds benefit from using the farm as a perching area or from feeding on epifauna growing on above water structures. Neither would be expected at offshore mussel farms which are submerged. Roycroft et al. (2007b) compared seabird activity budgets between three areas of nearshore mussel longline aquaculture and three control sites in Bantry Bay, Ireland. Divers were observed foraging in the mussel farm areas, and many seabirds perched at farms. Overall, they concluded the impact of mussel suspension culture appears to be positive or neutral on seabirds at the study site.

Fisher and Boren (2012) surveyed foraging distribution and habitat use of king shag *Leucocarbo carunculatus* in Admiralty Bay, New Zealand in relation to the many mussel farms there. Sitings of shags at farms was low and none were observed foraging in them, though the author states that a few observations of this behavior have been reported. Birds mostly used farm structures as perches to roost, rest, or preen. While there is concern about farms excluding seabirds from foraging habitat, Lloyd (2003) reported there are no published accounts of seabird entanglements in New Zealand aquaculture.

Spectacled eider

At nearshore suspended mussel farms, there may be wild sea ducks (i.e., eiders and scoters), which may prefer cultured mussels with thin shells and high flesh content over wild ones. At smaller farms, exclusion nets may be used to exclude birds. Varennes et al. (2013) evaluated eight types of exclusion nets of varying mesh size, thickness, color, and material using captive eiders in experimental tanks. They quantified and analyzed the birds' behavioral interactions with the different nets. Entanglement risk was generally low and occurred only at the surface. The best nets to avoid entanglement with eiders had large diameter twine and maximum mesh size of six inches that they could not swim through. Only one bird swam down 10m to get under the net. Color had no effect on behavior. The authors note that smaller mesh sizes (4 inches) are used to exclude smaller ducks in other countries. Other recommendations included in this paper are taut installation, frequent net maintenance, pairing with other exclusion methods such as scaring, and installation of nets only in high risk zones.

Richman (2013) provides recommendations for deterrent methods to reduce sea duck predation at mussel farms. Loud sound can frighten birds, but habituation can result. Visual devices such as streamers, plastic predators and mirrors are minimally effective. Human activity, boat chasing and falconry are very effective, but are labor intensive. Exclusion with nets is effective for small nearshore sites, but are expected to be less practical for large farm lease areas offshore. Shooting is highly effective at the individual level, but requires permits and may be unpopular.

Other Aquaculture Interactions

USFWS

American white pelicans

At marine fish farms, entanglement in the cage or anti-predator nets poses the biggest threat to seabirds, especially those that may dive to feed on fish or fouling organisms (Belle & Nash 2008, Northridge et al. 2013). Seabirds are reported to congregate near marine fish farms but are typically considered a low risk in terms of predatory threat, though they may scavenge mortalities or pick off fish during transfer or harvest (Pearson & Black 2001, Nash et al. 2005, Huntington et al. 2006, Rensel & Forster 2007). In contrast, the often significant impacts to freshwater aquaculture (Goldburg & Triplett 1997, Belant et al. 2000, Snow et al. 2005) and fisheries (Karpouzi et al. 2007) by piscivorous birds like cormorants and pelicans are better understood. Permits are available to implement non-lethal predator controls to frighten birds away from cages and, because birds become habituated to noise harassment, farms often use overhead netting or screens to exclude seabirds from cage areas (Nash 2001, Huntington et al. 2006, Halwart et al. 2007). Siting of fish farms away from important seabird habitats is encouraged or required in many countries (Bridger & Neal 2004, Borg et al. 2011) to minimize conflicts. Overviews of environmental impacts of marine aquaculture often refer to seabirds as species of concern, but contain few specific examples of measures implemented to aid in seabird conservation (Halwart et al. 2007, IUCN 2007). A recent monitoring study at southern Chilean salmon farms found that bird abundance was significantly higher near salmon farming areas than control sites (Jiménez et al. 2013). However, the species composition of the bird assemblages was different, with less diversity, and dominated by opportunistic generalists like gulls, vultures and cormorants. Hughes et al. (2014) collected video observations for 96 days at a pilot scale farm adjacent to land that cultivated algae for biofuel production. They documented visits by birds, sea otters and one sea lion. Birds tended to avoid any interaction with the farm gear, but gulls and coots were most likely to interact with the farm gear. Overall, there were no harmful interactions recorded, but the authors note they did observe that even this pilot scale operation affected behaviors like feeding, grooming and social activity.

USFWS

Northern gannet

A recent comprehensive report on the issue of seabird interactions with aquaculture was recently conducted in New Zealand (Sagar 2013). There have been very few

RON KNIGHT

Common eider

reports of seabird deaths as a result of entanglement in aquaculture facilities in New Zealand though the risk is acknowledged. Nonlethal effects include habitat exclusion and ingestion of marine debris. Potential benefits of aquaculture include the provision of roost sites closer to foraging areas and the attraction and aggregation of small fish to the farm, which are potential prey of seabirds. Table 10 summarizes the potential effects to seabirds and management options to reduce risk.

Overall, Sagar (2013) report concludes that harmful effects of existing aquaculture on seabirds are not presently considered significant. As with marine mammals loose and thin lines pose the greatest threat to diving seabirds. Hence, entanglement risk appears low in the New Zealand mussel industry where longlines are under considerable tension. Recommended management strategies include careful site selection to avoid threatened, endangered or protected bird species' home ranges, critical breeding and foraging habitats and migration routes. Minimizing marine debris, using minimal lighting at night, and using downward-pointing and shaded lights are also suggested and easily managed on a farm-by-farm basis.

Table 10 Overview of potential effects on seabirds from shellfish farming (adapted from Clement et al. 2013)

Effects	*Management Options*
Entanglement (resulting in birds drowning)	Careful site selection to avoid critical breeding and foraging habitats
Habitat exclusion	Ensure waste material and debris are collected and disposed of correctly
Providing roost sites closer to foraging areas	Minimize lighting at night
Aggregation of prey fish	Monitoring and reporting of negative interactions of seabirds with aquaculture structures

Sharks

We found no published reports on sharks being entangled in aquaculture gear, and there is little published information about the interactions of sharks and marine farms. Sharks have been documented as being attracted to fish cages in the Pacific Northwest (Nash et al. 2005), Puerto Rico (Alston et al. 2005), The Bahamas (Benetti et al. 2005), Latin America (Rojas & Wadsworth 2007) and Australia (Department of Sustainability, Environment, Water, Population and Communities 2013). Because sharks pose a threat to the stocked fish and potentially divers, dangerous species may be destroyed. In Australia, an estimated 20 great white sharks *Carcharodon carcharias* a year are killed at marine aquaculture farms (Department of Sustainability, Environment, Water, Population and Communities 2013). Siting of a salmon farm off South Africa within an ecologically significant great white shark congregation area and eco-tourist destination elicited major negative public response (Scholl & Pade 2005), and the farm was later closed. A telemetry study of sandbar *Carcharhinus plumbeus* and tiger *Galeocerdo cuvier* sharks near fish cages off Hawaii found that sharks did aggregate near the cages with some individuals being recorded for the entire term of the 2.5-year study (Papastimatiou et al. 2010). These animals were considered to pose minimal threat to humans.

Great white shark

The economic and ecological potential risk of large scale fish releases due to sharks tearing nets may be a concern as the industry moves into offshore sites (Holmer 2010) depending on the types of nets and locations used. Technological improvements in shark resistant aquaculture cage materials decreases the predation risk that sharks pose to aquaculture and may deter them from damaging farm equipment.

Shark guards are small rigid mesh nets installed at the bottom of a fish cage to prevent sharks from damaging nets while attempting to feed on dead fish that have fallen to the bottom (Jamieson & Olesiuk 2002). Good husbandry practices such as removing sick or dead fish promptly from cages is also an effective predator deterrent.

The extent to which sharks are attracted to farms to feed on wild fish and the resulting potential behavioral or ecological effects is unknown. Given the recent global interest in shark population declines and the need to implement conservation efforts, the potential impacts of marine cage culture to sharks is likely a fruitful area for research.

Other Marine Industry Sectors & Protected species interactions

The expansion of offshore energy production has raised concerns about impacts to marine protected species (Bailey et al. 2014). The information about interactions and mitigation in this industry sector may be applicable to marine aquaculture. Recent studies have addressed impacts of construction and operation of wind, tidal and wave energy technologies (Davis 2010, Dolman & Simmonds 2010, Simmonds & Brown 2011), pile-driving noise (Bailey et al. 2010, Thompson et al. 2010), methods to assess impacts (Evans 2008), and the frequency of occurrence (Cremer et al. 2009) and behavioral patterns at offshore facilities. Careful comprehensive investigation of this growing body of literature would likely prove to yield some insights that could be applied to learning more about protected species interactions with offshore aquaculture. Like energy producing structures in the ocean, marine aquaculture structures are three dimensional, stationary, and relatively permanent structures with human activity and noise. Opportunities for co-siting energy industries with aquaculture are of interest (Buck & Buchholz 2004).

Summary

Marine protected species may also be attracted to aquaculture structures as they can provide food, shelter or novel structures for exploration. As the scope of aquaculture activities increases in the open ocean, it is important to make decisions about mariculture within an ecological context. Little research has documented the extent to which marine predators target wild fish around farms, but this would be useful for understanding ecological interactions between farming and marine life. In contrast, impacts to predatory sharks and marine mammals are being minimized with improved net technologies that prevent predation on cultured fish. Proactive siting away from areas known to harbor dense populations of protected marine organisms is an effective strategy for minimizing negative interactions. Our current knowledge does not indicate significant impacts to marine mammals, sea turtles and seabirds from marine aquaculture structures and activities. Yet it is unclear if this is because farms are relatively benign and pose little risk, or because the number and density of farms is so low that the detection level for harmful interactions is also very small.

Further research into the mechanisms behind entanglement and other harmful interactions would provide valuable insight into how protected species might react to marine aquaculture gear. More in-depth analysis to discern which protected species are most prone to entanglement in and collision with fishery gear and in other marine industry sectors may focus efforts to avoid interactions with commercial aquaculture sites. A more technical consideration of longline mussel aquaculture gear, such as tension strength analysis for backbone lines, will provide useful information for understanding how protected species may interact with farm gear and lead to effective modifications to decrease harmful interactions. Research to better understand how marine species perceive farm structures visually and acoustically will likewise aid in developing strategies to avoid harm.

Although the last decade has seen an increase in the amount of information available about how protected species may be affected by off shore marine aquaculture gear, there are still many unanswered questions and uncertainty. There remains an overall a general lack of scientific reporting on entanglement frequency and severity of resulting injuries, mortality rates associated with interactions, effective deterrent methods, and technological innovation to reduce interactions and decrease harm if contact occurs. Importantly, negative data—scientifically collected data reflecting the lack of interactions with protected species—is also lacking. This makes it difficult to know if the paucity of reported incidents is due to low numbers of interactions or failure to detect and report them. However, the growth of the aquaculture industry worldwide is drawing attention to the potential environmental impacts of offshore aquaculture, including impacts to protected species. Spatial planning to inform siting and other mitigation will help resolve conflicts as the marine aquaculture industry grows.

This assessment is useful for guiding the regulatory process of protected species consultations to meet the goals of advancing aquaculture in the open ocean while still meeting legislative mandates for protected species. In addition to summarizing what is known and providing a state of science analysis, the risk assessment and knowledge gaps highlight the greatest potentials for harmful interactions between aquaculture and protected species, identify critical areas of research, and inform decisions about collaborative projects to further knowledge and protect imperiled species. The rising world population is becoming more reliant on aquaculture for food production. In the United States, the regulatory process for permitting offshore aquaculture facilities is moving forward and industry growth is expected. Domestic production of seafood can aid in decreasing U. S. reliance on imported products, provide jobs and food security, and meet the rising demand for seafood. Every effort should be made to ensure that industry growth occurs within a framework of environmental responsibility and ocean stewardship.

LESSONS LEARNED FROM FISHERY GEAR & APPLICATIONS TO AQUACULTURE

Background & Purpose

Because there are few documented cases of negative interactions of marine aquaculture and protected species like marine mammals, sea turtles and seabirds, regulatory agencies look to information on interactions between protected species and fishery gear to inform decision making. Marine megafauna, including marine mammals, sea turtles, seabirds and sharks, are known to interact directly with many types of marine gear, including fishery gear (Read 2008, Ledwell & Huntington 2010, Waring et al. 2012, 2015, Smith et al. 2014), resulting in collision, entanglement, injury, and death. Indirect effects are more difficult to assess but may include habitat exclusion, stress, behavioral changes, and delayed mortality.

Since some fishery gears, or components of the gear, are similar or analogous to aquaculture gear, it may be appropriate in certain instances to draw similarities between gear types as proxies, when determining relative risks to marine mammals to inform regulatory and management decisions with respect to aquaculture. However, much aquaculture gear is unique to that industry and direct comparisons to fishery gear may not be valid. One noteworthy difference is that aquaculture gear is largely stationary and deployed in the same place for periods spanning years or decades. In contrast, fishing gear such as trawls and trolls, which are towed, and longlines, which are deployed for a few hours in a location and then re-set, are highly transitory in the marine water column. Traps and gillnets are deployed for short durations, checked, and emptied before being reset often in different locations with a marker buoy attached at each end to visually identify each location. The lines attaching the marker

Biologists disentangling a North Atlantic right whale

buoys associated with fishing gear and other maritime activities (e.g., boating) are a well-documented entanglement risk. This kind of general purpose equipment can also be found at aquaculture facilities. These similarities and differences between gear types and deployment are important considerations, and add complexity to drawing direct comparisons between the two industry sectors.

There is value, however, in exploring similarities and differences between fishery and aquaculture gears to glean what we can from the former that can reasonably be applied to permitting, siting and management decisions about the latter. To this end, we reviewed research on fishery gear interactions with protected species to assess which lessons learned may be applicable to aquaculture gear. This review and analysis is not exhaustive, and is intended to provide a broad perspective as a foundation for future assessments.

THERE IS VALUE IN EXPLORING THE SIMILARITIES AND DIFFERENCES BETWEEN FISHERY AND AQUACULTURE GEARS TO GLEAN WHAT WE CAN FROM THE FORMER THAT CAN REASONABLY BE APPLIED TO PERMITTING, SITING AND MANAGEMENT DECISIONS ABOUT THE LATTER.

Harmful Interactions between Fishery Gear & Protected Species

It is widely known that fishery gear contributes significantly to human-caused injuries and mortalities to marine life (Soykan et al. 2008). Recent work provides excellent summaries of the lethal and non-lethal impacts of fishery gear to protected marine species (Johnson et al. 2005, Read 2008, Cassoff et al. 2011, Robbins & Kraus 2011, Reeves et al. 2013, Smith et al. 2014, Helker et al. 2015). Efforts are underway to quantify the numbers of interaction incidents and assess their severity (Robbins & Mattila 2001, Baker et al. 2010, Ledwell & Huntington 2010, Ledwell et al. 2013), reduce harmful interactions through gear modifications (Stone et al. 2000, Werner et al. 2006, Winn et al. 2008), and understand species-specific interaction risks (Robbins & Kraus 2011, Saez et al. 2013, Smith et al. 2014, Knowlton et al. 2015).

Cetaceans

Johnson et al. (2005) report that 89% (of 45 reported incidents) of humpback and right whale entanglements in the North Atlantic resulted from interactions with trap

Breaching humpback whale

and gillnet gear. Buoy lines (33%) and ground lines (16%) were more often identified as the portion of the gear remaining on the entangled animal than float lines (9%) or surface system (2%) lines. However, 40% of the time, the origin of the gear could not be determined. The authors conclude there is evidence to confirm that any sort of vertical lines in the water column pose a risk to the two whale species and that risk could be mitigated by decreasing occurrence of line in the water and placement of weak links in line systems.

The NMFS U. S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments (Waring et al. 2012, 2015) provide summaries of known marine mammal injuries and deaths. Direct mortalities and non-mortal injuries are difficult to assess, yet it is believed that entanglement is a leading cause of injury and death for large whales. From 2008–2012, the annual mortality and serious injury rates for baleen whales involving entanglement in the Gulf of Mexico coast, U. S. east coast and adjacent Cana-

dian waters was 3.85 right whales, 8.75 humpback whales, 1.55 fin whales, 0.4 sei whales, and 6.65 minke whales *Balaenoptra acutorostrata* (Waring et al. 2015). There are no entanglement reports in these five years for blue or Bryde's whales.

From 1990–2009, there were 94 observed right whale entanglements in weirs, gillnets, cod traps, lobster pot gear, and trailing lines and buoys (Waring et al. 2012). In contrast, only three of 45 right whale mortalities from 1970–1999 definitely involved entanglement in fishing gear (lobster and gillnet gear), though entanglement was also suspected as a secondary contributing factor in two mortalities involving ship strikes in those years. The annual rate of entanglement appears to have increased in the last decade compared to the end of the twentieth century. Humpback whales, especially yearlings and males, are prone to entanglement in fishing gear, possibly because they tend to roll when they encounter entangling fishing gear (Weinrich 1999, Clement 2013). Of 203 dead humpback whales where mortality could be definitively attributed from 1970 to 2009, about 57% involved entanglement with fishing gear (van der Hoop et al. 2013).

Waring et al. (2015) also provide entanglement data available for fin (9 entanglements), sei (2), minke (40), and sperm (3) whales resulting in serious injury or death in the Atlantic and Gulf of Mexico from 2008–2012. The U. S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments (Waring et al. 2012, 2015) additionally include data about dolphin and porpoise species, and pilot whales which are often caught in pelagic longline fisheries, gillnets and trawls. Similarly, hundreds of gray, harbor and harp seals perish in fisheries each year (Waring et al. 2012, 2015).

Entanglement undoubtedly poses a threat to protected species. It is known that animals frequently survive entanglement because scarring patterns can readily be assessed during necropsies, photo identification, and field observation. For instance, Knowlten et al. (2005) found that 75.6% of whales had scars indicating they had been entangled at least once. In Canada, Vanderlaan et al. (2011) examined the risk of lethal entanglement for right whales in fishery gear. The analysis used spatial overlap between fishing season, area of gear deployment, and whale critical habitat to identify fisheries of greatest threat to whales. They determined that groundfish hook and line gear (i.e., bottom longline gear) is the greatest threat during the summer residency period of right whales, while the lobster trap lines are the greatest threat during migratory periods in spring and fall. This spatial and temporal risk assessment approach could be adapted to analyze the areas where aquaculture gear could be deployed to reduce risk of harmful interactions with right whales or other protected species.

ENTANGLEMENT UNDOUBTEDLY POSES A THREAT TO PROTECTED SPECIES.

Knowlton et al. (2012) examined photographs of 626 north Atlantic right whales taken from 1980–2009 finding that 83% had been entangled. Juveniles were entangled at higher rates than adults. Over half the whales had been entangled more than once, and a quarter of the whales acquired new scars each year. The authors calculated an annual entanglement rate of 25.9% for animals with adequate photographic data collected in consecutive years, thus allowing definite evidence that entanglement scarring had occurred between the dates of sequential pictures. During this time, there were 86 known serious entanglement incidents, the frequency of which has increased since the mid-1990s.

An early study of humpback whale entanglement in the main Hawaiian islands from 1972–1996 reported 7 entangled whales (at least two entangled in fishery gear) of 26 total whales injured or dead (Mazzuca et al. 1998). The authors noted an increasing trend over the 25-year period in annual frequency of entanglement in lines. Two of the entangled whales had shark injuries and a third was noted to have large tiger sharks swimming near it during attempts to disentangle the animal. The authors note that if entanglement stresses and weakens whales they may be at higher risk for shark predation. Studies of Gulf of Maine humpback whales used scar-based entanglement evidence to estimate an annual entanglement mortality rate of 3%,

Right whale entangled in line

equaling 19–29 deaths per year (Robbins & Mattila 2001, Robbins et al. 2009). In Argentina, of 9 southern right whale entanglement incidents from 2001–2011 at least 2 resulted from fishery gear including ropes, buoys and nets (Bellazzi et al. 2012). A third, possibly involved mussel spat collection lines, but this was not definitively confirmed. Two involved rope which could not be attributed to a specific human activity and the other 4 were due to vessel moorings.

A global summary of data on marine mammal bycatch in entangling fishing gear (primarily gillnets) spanning from 1990 to 2010 was compiled by Reeves et al. (2013). This study shows the significant risk that entangling gear poses for marine mammals. The authors note that humpback, right and minke whales seem especially prone to entanglement though the explanation for this is not clear. Johnson et al. (2005) found that humpback whale entanglements were more likely to involve the tail than right whales which tended to involve the mouth more frequently, although the original gear configurations were not known in most cases.

Robbins and Kraus (2011) discuss numerous behavioral, sensory, and morphological characteristics of right and humpback whales that may explain how these species perceive and respond to fishing gear. For example, right whale mouth morphology and feeding behavior suggest they often swim with their mouths open, putting them

BRIAN GRATWICKE

Loggerhead Sea Turtles

BRIAN GRATWICKE

at higher risk of mouth entanglement. Flipper size and shape, skeletal flexibility and sensitivity to light and color are variable in marine mammals and other protected species, and improved understanding of how these affect entanglement risk are needed. The authors note that making gear more visible to whales or developing ropeless fishing gear could significantly decrease entanglements.

Entanglement of marine mammals in lines may result in death by drowning, but can also cause impaired locomotion, decreased ability to forage, tissue infection and necrosis all which may lead to traumatic injuries, prolonged suffering and starvation leading to death (Cassoff et al. 2011). Thus, interactions with aquaculture gear must consider the potential for both immediate mortality as well as secondary impacts.

Sea Turtles

Sea turtles also interact with fishing gears when their distribution overlaps with fishing effort. Lewison et al. (2014) used empirical data from peer-reviewed publications, agency and technical reports, and symposia proceedings published between 1990 and 2008 to identify the global distribution and magnitude of sea turtle bycatch in gillnets, longlines, and trawls. High-intensity sea turtle bycatch was most prevalent in the southwest Atlantic Ocean, eastern Pacific Ocean, and Mediterranean Sea. Considering bycatch intensity by gear categories (longline, trawl, and gillnet) worldwide, Lewison et al. (2014) found gillnets had the highest bycatch intensity scores, followed by longlines, and then trawls.

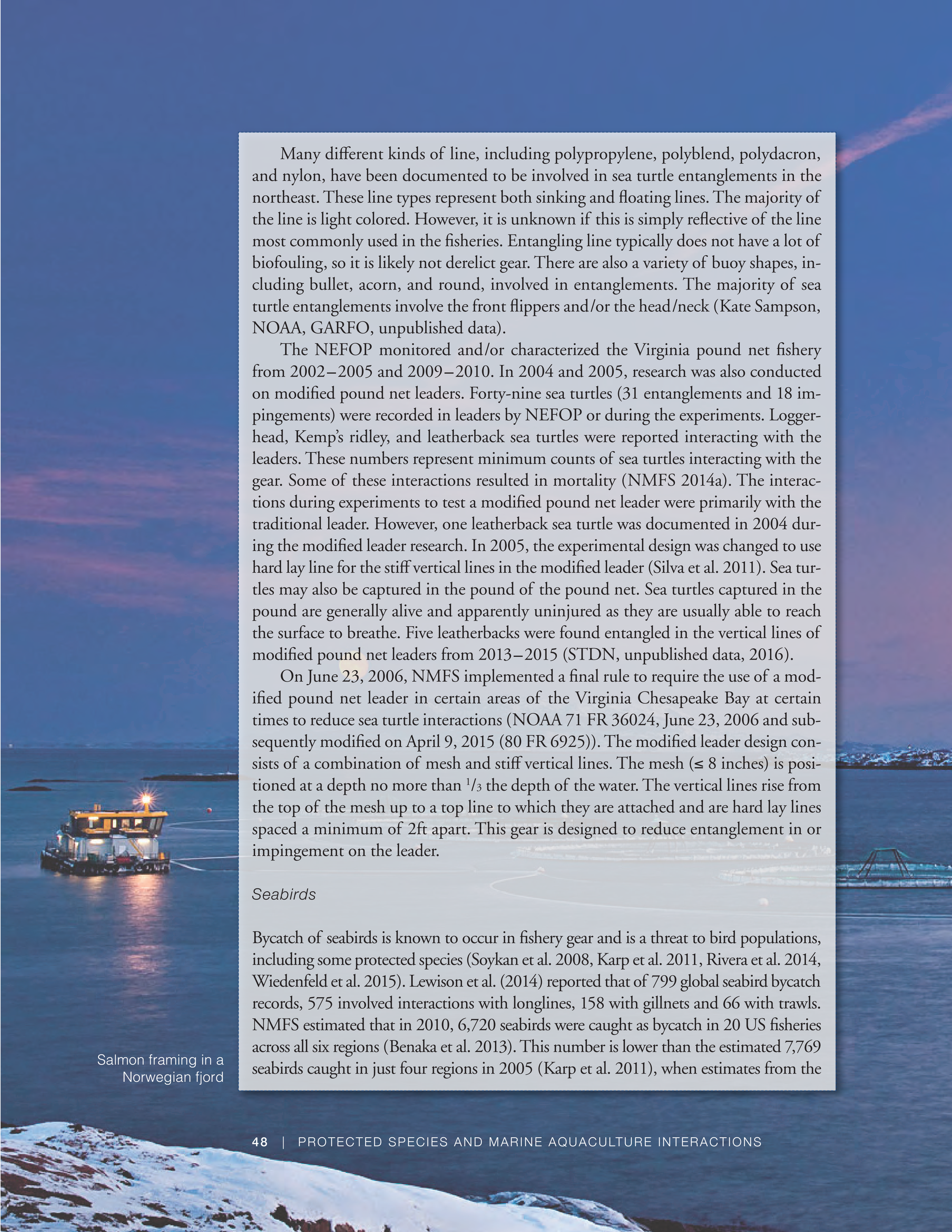
In the U. S. northeast region, sea turtles interact with several fixed gears, including gillnets, pots, and pound net/weirs. While sea turtles are also known to interact with mobile gears, those gears are less similar to the gears used in aquaculture. NMFS' Northeast Fisheries Observer Program (NEFOP) observers and at-sea monitors have reported loggerhead, leatherback, Kemp's ridley, and green sea turtles in gillnet gear. Bycatch estimates are available for loggerhead sea turtles, indicating serious injury and mortality may result from these interactions.

INTERACTIONS WITH AQUACULTURE GEAR MUST CONSIDER THE POTENTIAL FOR BOTH IMMEDIATE MORTALITY AS WELL AS SECONDARY IMPACTS.

Following the methods in Upite (2011) and Upite et al. (2013), the Northeast Sea Turtle Serious Injury Workgroup reviewed sea turtle interactions recorded by fisheries observers to determine serious injury and mortality percentages. Using interaction records from 2010–2014, the mortality in gillnet gear was estimated to be 84%, an increase from previous estimates ranging from 57–65% (Carrie Upite, NOAA, GARFO, unpublished data).

Murray (2009) estimated that from 1995 to 2006, the average annual bycatch estimate of loggerheads in all U. S. mid-Atlantic gillnet gear was 350 turtles. More recently, Murray (2013) estimated interactions between loggerhead and other hard-shelled turtles and commercial gillnet gear in the mid-Atlantic from 2007–2011 using data collected by NEFOP observers and at sea monitors. Turtles observed were alive with or without injury, dead, or of unknown condition, and were mainly entangled by their head or flippers in the net mesh, free of the floatlines or lead lines. The field data was used in a general additive model to estimate that an annual average of 95 hard-shelled sea turtles, 89 of which were loggerheads, interacted with gillnet gear, resulting in an estimated 52 loggerhead mortalities. Highest interaction rates were estimated in the southern mid-Atlantic, in warm surface waters, and in large mesh gillnets consistent with the earlier Murray (2009) findings. Murray and Orphanides (2013) built models using fishery dependent and independent data collected between 1995–2007 to predict that the highest bycatch in commercial gillnet, dredge, and trawl gears, totaling 44 loggerheads per year, occurs in warm waters of the southern mid-Atlantic. Explanatory variables for encounter rates between turtles and gear were latitude, sea surface temperature, depth and salinity.

Sea turtles may also become entangled in vertical lines in the water column (NMFS 2015). In response to high numbers of leatherback sea turtles found entangled in the vertical lines of fixed gear in the northeast, NMFS established the Greater Atlantic Region Sea Turtle Disentanglement Network (STDN). Formally established in 2002, the STDN works to reduce serious injuries and mortalities caused by entanglements. From 2002 through 2014, the STDN documented 275 entanglements in vertical lines (Kate Sampson, NOAA, GARFO, unpublished data). Most of these lines are from pot fisheries (143) or are of unknown origin (131). One documented interaction was in aquaculture gear. Other lines in the water have also been documented interacting with sea turtles. These include modified pound net leaders, dive line, mooring line, and mooring surface systems. The majority of interactions are with leatherback sea turtles with green and loggerhead turtles being documented to a lesser extent. In general, hard-shell sea turtle entanglements are seen more commonly in the southern part of the northeast region.



Salmon framing in a Norwegian fjord

Many different kinds of line, including polypropylene, polyblend, polydacron, and nylon, have been documented to be involved in sea turtle entanglements in the northeast. These line types represent both sinking and floating lines. The majority of the line is light colored. However, it is unknown if this is simply reflective of the line most commonly used in the fisheries. Entangling line typically does not have a lot of biofouling, so it is likely not derelict gear. There are also a variety of buoy shapes, including bullet, acorn, and round, involved in entanglements. The majority of sea turtle entanglements involve the front flippers and/or the head/neck (Kate Sampson, NOAA, GARFO, unpublished data).

The NEFOP monitored and/or characterized the Virginia pound net fishery from 2002–2005 and 2009–2010. In 2004 and 2005, research was also conducted on modified pound net leaders. Forty-nine sea turtles (31 entanglements and 18 impingements) were recorded in leaders by NEFOP or during the experiments. Loggerhead, Kemp's ridley, and leatherback sea turtles were reported interacting with the leaders. These numbers represent minimum counts of sea turtles interacting with the gear. Some of these interactions resulted in mortality (NMFS 2014a). The interactions during experiments to test a modified pound net leader were primarily with the traditional leader. However, one leatherback sea turtle was documented in 2004 during the modified leader research. In 2005, the experimental design was changed to use hard lay line for the stiff vertical lines in the modified leader (Silva et al. 2011). Sea turtles may also be captured in the pound of the pound net. Sea turtles captured in the pound are generally alive and apparently uninjured as they are usually able to reach the surface to breathe. Five leatherbacks were found entangled in the vertical lines of modified pound net leaders from 2013–2015 (STDN, unpublished data, 2016).

On June 23, 2006, NMFS implemented a final rule to require the use of a modified pound net leader in certain areas of the Virginia Chesapeake Bay at certain times to reduce sea turtle interactions (NOAA 71 FR 36024, June 23, 2006 and subsequently modified on April 9, 2015 (80 FR 6925)). The modified leader design consists of a combination of mesh and stiff vertical lines. The mesh (≤ 8 inches) is positioned at a depth no more than 1/3 the depth of the water. The vertical lines rise from the top of the mesh up to a top line to which they are attached and are hard lay lines spaced a minimum of 2ft apart. This gear is designed to reduce entanglement in or impingement on the leader.

Seabirds

Bycatch of seabirds is known to occur in fishery gear and is a threat to bird populations, including some protected species (Soykan et al. 2008, Karp et al. 2011, Rivera et al. 2014, Wiedenfeld et al. 2015). Lewison et al. (2014) reported that of 799 global seabird bycatch records, 575 involved interactions with longlines, 158 with gillnets and 66 with trawls. NMFS estimated that in 2010, 6,720 seabirds were caught as bycatch in 20 US fisheries across all six regions (Benaka et al. 2013). This number is lower than the estimated 7,769 seabirds caught in just four regions in 2005 (Karp et al. 2011), when estimates from the northeast and southwest were not available. Croxall et al. (2012) conclude that more than 80 species of coastal and pelagic seabirds are threatened by mortality in fishing gear, and identify continued bycatch reduction as a priority management need.

Bycatch of seabirds in gillnets is known to occur through entanglement in the netting (Hall and Mainprize 2005, Løkkeborg 2011). Warden (2010), reports that from 1996–2007, the average annual gillnet bycatch in the northeast was 74 common loons *Gavia immer*, and in the Mid-Atlantic annual estimates are 477 common and 897 red-throated loons *G. stellate.* The red-throated loon is a species of conservation concern, and these mortality estimates reflect about 60% of the Potential Biological Removal (PBR) levels. Žydelis et al. (2009) estimated that coastal gillnet fisheries in the Baltic and North Seas may catch more than 90,000 seabirds per year. A global review of seabird bycatch suggests as many as 400,000 birds may die in gillnets annually (Žydelis et al. 2013). At a recent workshop to address bycatch reduction of marine life, proposed methods to decrease seabird bycatch in gillnets included net striping, pingers, high-visibility net sections, lighting and dropped headlines (Wiedenfeld et al. 2015). Because bycatch reduction approaches for longlines often seek to reduce hooking (Hall and Mainprize 2005, Lewison et al. 2004, Løkkeborg 2011), there may be few applications to aquaculture gear. Trawl fisheries bycatch primarily tends to involve collision with towing cables (Løkkeborg 2011), which is also dissimilar to gear at aquaculture facilities, but can also result from entanglement in trawl netting.

Løkkeborg (2011) provides an overview of measures that have been tested in longline, trawl and gillnet fisheries, and reviews their fishery suitability and efficiency in mitigating bycatch of seabirds. He notes that bycatch reduction can be extremely effective, often reducing bycatch by more than 80% with little impact to target catch rates. This conclusion is supported by NMFS data from Alaska and Hawaii where significant reductions in seabird bycatch were achieved through collaborations with fishing industry groups, gear technologists, scientists, seabird biologists, and environmental conservation groups (NMFS 2008a). Though the primary trust responsibilities for seabirds lies within the USFWS, NMFS recognizes seabirds are ecosystem indicators and a vital part of healthy ocean ecosystems. Therefore, NMFS is concerned about the long-term ecosystem effects of seabird bycatch in fisheries, and managing the marine habitats that seabirds depend on within the U. S. EEZ (Rivera et al 2014, NMFS 2014b).

Vessel Strikes

Another large source of injury and mortality to marine species is vessel strikes (Waring et al. 2012, 2015). Marine aquaculture facilities inherently require the use of small and large vessels to transport materials, fish, feed, harvesting equipment, and maintenance crews between farm sites and shore. This vessel traffic could also potentially impact protected species and is considered in permit review and consultations. Ensuring that no feed, live fish or carcasses are released from farm vessels during stocking, transport or harvest should decrease attraction of farm vessels to marine animals opportunistically seeking food sources.

ENSURING THAT NO FEED, LIVE FISH OR CARCASSES ARE RELEASED FROM FARM VESSELS DURING STOCKING, TRANSPORT OR HARVEST SHOULD DECREASE ATTRACTION OF FARM VESSELS TO MARINE ANIMALS OPPORTUNISTICALLY SEEKING FOOD SOURCES.

Fishery Gear: Similarities with Aquaculture Gear

Of the six commonly used gear types, most mobile gear has few similarities with aquaculture gear (Table 11). This gear includes trawls, trolls and dredges, which are towed through the water column or along the sea floor with bycatch of protected species as the primary source concern. These are unlike stationary farm facilities. Harmful interactions with pelagic longline fishery gear typically involve marine fauna becoming hooked while foraging on bait or catch. Neither of these mechanisms for harmful interaction is a risk at aquaculture operations, since the deployment and capture methods of these gears is not comparable to farm activities. Finfish farms that raise fish in floating cages or net pens suspended at the surface are fully enclosed and typically include a predator net covering each cage to prevent birds from foraging at the surface inside of the cage. Since net pens are constructed to contain fish inside the cage, multifilament mesh panels are sewn together to create a complete enclosure preventing fish from escaping and preventing marine mammals from entering and becoming trapped. Similarities to longline mussel aquaculture for this gear type are to the anchoring system and associated lines under high tension. Encircling nets to capture fish with boats are not similar to net pens or cages used in commercial fish farming.

According to recent reviews compiled for this assessment, one of the greatest risks of fixed fishery gear for protected species is entanglement in anchoring and buoy lines, which bear similarity to some structures at marine farms. Most anchors used at farm sites are fixed structures engineered from heavy gravity or plow anchors, attached to the gear with thick metal cables or high tensile strength line, and typically under high tension (Ögmundarson et al. 2011). These lines are not likely to pose entanglement risk. They may, however, pose more risk to the animal from collisions resulting in lacerations, scrapes and bruising type injuries (Winn et al. 2008, Baldwin et al. 2012). Investigations of other marine industries which employ similar high tension, metal cables as anchoring systems could yield insight into how protected species are affected by these structures, including how they may perceive, respond to and interact when encountering such obstacles. Buoy lines marking farm boundaries or individual cage positions in mussel longline operations are similar to those used to mark traps, pots and gillnets, and may pose similar risks from entanglement to protected species as mentioned above. Further, loose or unattended lines used in daily operations (tying up vessels, for example) are a potential entanglement hazard. Prevention of these around farm sites has been identified as a Best Management Practice for marine aquaculture (Clement 2013, Price & Beck-Stimpert 2014).

ONE OF THE GREATEST RISKS OF FIXED FISHERY GEAR FOR PROTECTED SPECIES IS ENTANGLEMENT IN ANCHORING AND BUOY LINES, WHICH BEAR SIMILARITY TO SOME STRUCTURES AT MARINE FARMS.

The thin diameter monofilament mesh of gillnets bears little resemblance to the heavier multifilament net material used at fish farms (Lekang 2013). Modern anti-predator cages and netting are rigid enough when deployed tautly to avoid entanglement. In contrast, gillnets are deployed to be more flexible in the water column to facilitate entanglement of target species. Marine mammals entangled in gillnets often opportunistically forage on caught fish (Read et al. 2003, Pennino et al. 2015) but this is not a scenario at either shellfish or finfish farms. Studies indicate dolphins are

Table 11 Fishery gear impacts to protected marine species and similarities to aquaculture gear.

Commercial Fishery Gear Type	*Harmful Impacts to Protected Species*	*Differences and Similarities*
Traps/Pots	Entrapment Entanglement in buoy lines	• Aquaculture anchoring system use larger diameter lines under tension. • Farm marker buoy lines and spat lines may be similar and pose entanglement risk.
Gillnets	Entanglement in netting Entanglement in marker buoys or anchor lines	• Aquaculture cage nets are generally taut and utilize small mesh to contain fish. • Aquaculture anti-predator nets are generally deployed very taut and large mesh sizes are used to exclude large animals. • Farm nets and other gear lost as marine debris pose entanglement and ingestion risk. • Farm marker buoy lines and spat lines may pose similar entanglement risk.
Hook and Line	Entanglement in fishing lines. Ingestion of bait or catch and gear like hooks	• Aquaculture anchoring system use larger diameter lines under tension. • Buoy lines and spat collection lines may cause similar entanglement.
Encircling Nets	Entrapment inside net; Entanglement in net material	• Pinnipeds and dolphins may leap over rims of surface cages but this is prevented by using high railings around floating walkways and covering nets. • Techniques for removing non-target animals from encircling nets also useful if animals trapped in aquaculture pen.
Pelagic Longlines	Ingestion of bait or catch	• Aquaculture longlines are tensioned, stationary, and gear; foul hooking; and larger diameter entanglement.
Trawls, Trolls and Dredges	Capture in net or dredge bag, entanglement in lines, impact with gear	• Aquaculture gear is stationary and not open to the water column.

often able to successfully maneuver around or avoid fishing nets (Read et al 2003, Byrd & Hohn 2010) suggesting the three dimensional structure of farms might be readily perceived and avoided by some species. Modern cage and anti-predator netting are typically made of strong, rigid synthetic materials designed to withstand ocean conditions for years (Lekang 2013, Belle & Nash 2008). Cage nets are kept taut by using weights or other technology at the bottom of the net bag to maintain shape in the water column. Anti-predator nets similarly are deployed taut to prevent bowing or folding in currents, and are deployed with space between them and the fish containment nets or cages. Tensioned deployment prevents predators from being able to bite or push into nets when trying to access fish, thus reducing entanglement risk. Anti-predator mesh sizes range from 3.8–20cm (bar length) depending on the target species for exclusion (Belle & Nash 2008).

CONTINUED COMPARISONS BETWEEN AQUACULTURE AND FISHERY GEAR ARE NEEDED TO THOROUGHLY EVALUATE THE SIMILARITIES AND DIFFERENCES BETWEEN ALL COMPONENTS OF AQUACULTURE AND FISHING GEAR, AND TO ASSESS THE POTENTIAL RISK ASSOCIATED WITH ALL GEAR INTERACTIONS.

Uncertainty remains about the risk posed by horizontal backbone lines at mussel farms. Some believe the high tension associated with these lines decreases entanglement risk. While this may be true for smaller animals, there is still concern that very large whales may still be at risk for entanglement (and injury) if they collide with horizontal lines at mussel farms (Erin Burke, Massachusetts Department of Fish and Game, pers. comm.). Other types of horizontal lines such as floating groundlines connecting lobster pots are seasonally prohibited by NOAA to reduce entanglement. Continued comparisons between aquaculture and fishery gear are needed to thoroughly evaluate the similarities and differences between all components of aquaculture and fishing gear, and to assess the potential risk associated with all gear interactions.

Like lost fishery gear, aquaculture gear improperly disposed of or lost from a facility contributes to marine debris (Cerim et al. 2014). It is difficult to determine the commercial fishing industry sector of origin of a buoy line or loose rope; however, litter, such as feed bags, may be traced back to aquaculture activities. While it is established that marine wildlife is impacted by marine debris through entanglement, ingestion, bioaccumulation, and habitat effects (Vegter et al. 2014), the relative contribution of aquaculture gear to marine debris is unknown. Macroplastic debris contributes to entanglement, and both micro- and macro-debris are ingested by marine species. Strategies for reducing marine debris from fishery activity may transfer well to aquaculture activities.

Gear Modifications

There is keen interest in modifying fishery gear and adjusting how it is deployed to decrease harmful interactions with marine life and decrease bycatch of non-target animals. Werner et al. (2006) summarized 55 modifications to fishery gear that could be used to decrease unintended injuries and fatalities to non-target species. These include proven and experimental techniques based on sensory aversion (e.g., acoustic or visual deterrents), physical exclusion (fences), gear designed to break under pressure, galvanic release technology, and waste management (offal removal) approaches (Table 12). It is likely that some of these modifications could also be incorporated

Table 12 Fishery gear modifications to reduce interactions with marine wildlife that may be adapted for use in aquaculture. G=gillnets, TP=traps/pots, E=encircling nets, T=trawls, D=dredges, H=hook and line including longlines. Adapted from Werner et al. 2006.

	Bycatch Reduction Technique	*Fisheries*	*Aquaculture Potential*
AVOID CONTACT	**Acoustic**		
	Pingers/alarms	G, TP, T	Acoustic devices to deter marine mammal predators have been tested at fish farms, but effectiveness is highly variable. Habituation is documented. Sounds may attract predators to farms. Harm to non-target species may occur.
	Acoustic harassment devices	G, E, TP, T	
	Passive acoustic deterrents	G, TP	
	Vessel noise reduction	G, E	
	Animal predation sounds	G, TP	
	Echolocation disruptor	G	
	Pyrotechnics	G, E, TP	
	Visual		
	Glow rope	G, TP	Predator models ineffective. Increasing the visibility of gear is a potential area for research. Increasing visibility could attract curious animals.
	Bird-scaring devices	H	
	Lightsticks	G	
	Reflective/colored buoys	H	
	Quick release metal wire	H	
	Olfactory		
	Scent deterrents	TP	Deterrent effectiveness is unknown
	Gustatory		
	Noxious bait	H	Deterrent effectiveness is unknown
	Tactile		
	Animal prodding	E, D	These methods might cause undue harm to marine mammals
	Electromagnetic deterrents	G, E, TP, T, H	
	Physical Exclusion		
	Buoy line message system	G, TP	Physical exclusion of marine mammals using rigid nets is effective for avoiding predation and avoids negative interactions. Additional technologies and methods could be investigated for aquaculture applications. Submerged technology for fish and shellfish are being used.
	Acoustic release	G, TP	
	Alternative offal discharge	H	
	Sinking/weighted lines	TP, H	
	Decoy deterrents	G, E, H	
	Vessel chasing	G, H	
	Deep-water sets	G, H	
	Remote attractor devices	E	
	Fence/net barriers	TP	
	Trap guards	TP	
	Fleet communication	E, T, D, H	
ESCAPE CONTACT	Excluder devices	T, D	Technology to enable escape could be integrated into some aquaculture gear, and this is an area of potential research. More detailed analysis of gear similarities and differences is needed.
	Break-away lines	G, TP	
	Time tension line cutter	G, TP	
	Buoy line trigger release	G, TP	
	Stiff rope	G, TP	
	Medina panel	E	
	Alternative net filaments	G	
	Galvanic release	G, TP	
	Lipid soluble rope	G, TP	

Worker conducting maintenance on a submersible cage

Diver inspecting offshore netpen

Almaco Jack (*Seriola rivoliana*) being raised in netpen into aquaculture gear development for the same purposes. Of the techniques identified by Werner et al. (2006), 28 have been noted in Table 12 as having potential application to marine farms. For example, break away rings integral to the lines are designed to break under the tension loads resulting from large animals like whales coming in contact with buoy or anchor lines on fishing gear. Break away technology could similarly be incorporated at the buoy lines or gear anchoring systems at marine farms. Breakaway lines have been included in proposals for offshore mussel farm gear configuration, but it is unknown how often they are used. Modifications may be advantageous for farms as well as the animals as it may decrease damage to expensive farm gear. Some of the techniques such as acoustic deterrents are already being used—albeit with varying levels of success—at fish farms. The paper provides details of several dozen validation studies that may be useful for informing research and testing gear modifications to reduce negative interactions at farms.

Technology to enable escape could be integrated into some aquaculture gear, and this is an area of potential research. More detailed analysis of gear similarities and differences is needed. The NOAA/NMFS Protected Resources Division Gear Research Team conducts and coordinates research and field trials on gear modifications that decrease harm to protected species (Salvador et al. 2002, 2003a, 2003b, 2006, 2008). Their work is done in collaboration with researchers from other agencies and institutes and commercial fishers. Gear research projects have included testing different line materials, gear deployment strategies, netting materials, break away link designs, and time-release buoy systems. Gear types are tested on land and in water under varying loads to simulate the load forces of protected marine species. Alternative netting and line materials are deployed to evaluate their visibility and durability underwater. The mechanical, acoustic, time-release and galvanic weak link designs evaluated for use in fishery gear may also be useful for application at fish farms. Research has been done to better understand how certain species (especially species at high risk like humpback and right whales) interact with and are affected by specific gear. For example, data from studies looking at how different line materials affected baleen and skin tissues may be applied to aquaculture gear.

MODIFICATIONS MAY BE ADVANTAGEOUS FOR FARMS AS WELL AS THE ANIMALS AS IT MAY DECREASE DAMAGE TO EXPENSIVE FARM GEAR.

Recent research on the relative strength of ropes used in fishing gear and involved in entanglement of right and humpback whales found that injuries are more severe since the 1990s as material technology advanced to produce stronger ropes (Knowlton et al. 2015). The authors recommend using ropes with breaking strengths of less than 1700lbs to reduce the lethal entanglements risk to large whales by up to 72%. This modification could reduce whale mortality resulting from entanglement to below the PBR levels defined by NMFS, though no consideration was used for the real world feasibility of this reduced breaking strength line for fishing. Also, benefits to smaller whales (including juveniles), smaller marine mammals and sea turtles (Karp et al. 2011) may not be realized due to smaller body size. Any modifications to gear type may also need to take into account if and how the safety of commercial fishers may be affected. Such considerations for gear modification may also be applicable to marine aquaculture where similar types of lines may be used for marker buoys, farm maintenance and vessel operation.

Whale's tail

Winn et al. (2008) used flippers and fluke tissues from adult and juvenile right whales, and a humpback whale collected during necropsy to assess relative impacts to the tissue under varying types of laboratory simulations of synthetic lines like those used in fisheries for float and ground lines. The calf tissue was most vulnerable, the adult right whale was most resilient, and the humpback tissue was intermediate. Baldwin et al. (2012) conducted lab and field experiments with life-sized models of right whale flippers to test how taut versus slack vertical 5/8 lines, such as those used for floating buoys to mark fishing gear like lobster pots, might interact differently with whale flippers. The results of the study suggested that increased line tension (around 325lbs in the trials) has the potential to cause significant laceration and perhaps embedment of line into flippers, even with only glancing contact. Making fishing gear more visible and developing rope-less fishing gear have been suggested to reduce entanglement (Robbins & Kraus 2011). Both approaches would likely be advantageous in aquaculture operations as well. While fishery gear may not be as effective at catching target species if it is highly visible, this should not be an impediment to development of high visibility aquaculture technology. Additional information about vision and color detection and response in protected species could inform development of farm technology that would be more visible to protected species and, hopefully, induce avoidance behavior.

ADDs have been deployed in both fishery and aquaculture settings (see previous discussion of efficacy at fish farms) to avoid harmful interactions with marine mammals. In both sectors, results have been mixed. The range of effectiveness of ADDs in aquaculture is discussed previously. Pingers have been found to be effective at decrease in bycatch of marine mammals but are not 100% effective (Karp et al. 2011, Waring et al. 2012, 2015). However, pingers in gillnets have been found ineffective at deterring humpback whales (Harcourt et al. 2014), suggesting that, as with aquaculture, effectiveness of ADDs is variable and species specific.

Gear modifications and deterrents have also been investigated as methods to reduce sea turtle bycatch in fixed gear. These have been the focus of discussions at several workshops (NMFS 2008b, Gilman 2009, NMFS & ASMFC 2013, Wiedenfeld et al. 2015). The workshop reports summarize the research to date and the potential mitigation tools identified. Gear modifications proposed, and in many cases tested, include increasing gear visibility (e.g., illumination), utilizing acoustic deterrents, reducing net height, eliminating tie-downs, modifying float characteristics, changing set direction, and reducing the breaking strength of the mesh. Gilman (2009) summarizes research involving modifications to gillnet and pound net gear designs to reduce sea turtle catch rates without compromising the economic viability.

In the mid-Atlantic, low profile gillnets have been explored to reduce sea turtle bycatch in large mesh gillnet fisheries. The low profile nets were 8 meshes high with 24” tie-downs; the control net was 12 meshes high net with 48” tie-downs. No sea turtles were captured in either net during the study (He & Jones 2013) so the gear could not be analyzed for bycatch reduction. Recent studies have also evaluated the use of visual deterrents and preliminary work has begun on acoustic deterrents. Wang et al. (2013) examined the effectiveness of illuminating gillnets with ultraviolet light-emitting diodes for reducing green sea turtle interactions. The sea turtle capture rate was reduced by approximately 40% in UV-illuminated nets compared to nets without illumination. Earlier studies evaluated the use of LED and chemical light stick illumination to reduce sea turtle bycatch. Mean sea turtle bycatch was significantly reduced by 60% in the nets illuminated by chemical light sticks and by 40% in the nets illuminated by LED lights (Wang et al. 2010). These studies suggest that net illumination may have applications in reducing sea turtle bycatch. Wang et al. (2010) also evaluate the use of shark shapes on the nets to reduce bycatch. The presence of shark shapes reduced the mean catch rates of sea turtles by 54% but also reduced target catch.

ADDITIONAL INFORMATION ABOUT VISION AND COLOR DETECTION AND RESPONSE IN PROTECTED SPECIES COULD INFORM DEVELOPMENT OF FARM TECHNOLOGY THAT WOULD BE MORE VISIBLE TO PROTECTED SPECIES AND, HOPEFULLY, INDUCE AVOIDANCE BEHAVIOR.

As described above, vertical lines have the potential to entangle sea turtles. In 2008, NMFS GARFO sponsored a workshop on interactions between sea turtles and vertical lines of fixed gear fisheries. One focus of the workshop was on preventing entanglements. Potential options for reducing entanglements included stiffening the line, sheathing the line (i.e., encasing lines in rigid or semi-rigid material similar to PVC or hose), decreasing vertical line density, using sinking breakaway line, and the use of acoustic and visual deterrents (NMFS 2008b, NMFS 2015). These mitigation techniques may have potential for reducing sea turtle bycatch in aquaculture gear.

Cooperative field observations and trials, such as those conducted by the NMFS PRD Gear Research Team, of fishing gear and deployment methods have been conducted to evaluate *in situ* the potential for entanglement, and provide opportunity for fishers and biologists to jointly identify modifications that can decrease entanglement risk with the minimal impact to catch and safety. A similar approach has been initiated in Maine to involve lobster fishers in identifying, developing and testing innovative gear and methods to reduce bycatch and entanglement (McCarron & Tetreault 2012). This cooperative approach to research and development and post-implementation monitoring (Soykan et al. 2008) is recommended for development of similar approaches to decrease risk and harm of interactions between protected species and fish farms. Observer programs have been an important part of understanding and quantifying fishery gear interactions with protected species (Reeves et al. 2013). Though the marine aquaculture industry is very small in the United States currently, a similar approach may be useful for monitoring interactions once it has scaled up.

Further research into the mechanisms behind entanglement and other harmful interactions would provide valuable insight into how protected species might react to marine aquaculture gear. More in-depth analysis to discern which protected species are most prone to entanglement in and collision with fishery gear and in other marine industry sectors may focus efforts to avoid interactions with commercial aquaculture sites. A more technical consideration of longline mussel aquaculture gear, such as tension strength analysis for backbone lines, will provide useful information for understanding how protected species may interact with farm gear and lead to effective modifications to decrease harmful interactions. Research to better understand how marine species perceive farm structures visually and acoustically will likewise aid in developing strategies to avoid harm.

Preliminary Risk Assessment, Knowledge Gaps & BMPs

Possible Risks To Protected Species from Offshore Longline Mussel Aquaculture in U.S. Waters

- There may be risk to marine mammals from marine aquaculture, in terms of mortality and injury, from legal and illegal shooting of predatory pinnipeds. Currently depredation permits authorizing lethal take are not issued to aquaculture facilities in the United States. This is not expected to be an issue at offshore mussel longline farms which do not attract predatory marine mammals, and is thus a relatively low risk at U.S. mussel farms.
- Habitat exclusion can range from low to high risk depending upon the location and density of mussel farms. Existing studies have demonstrated the potential for protected species to be excluded from foraging habitats, but all the studies were conducted in nearshore waters. It is uncertain how, or even if these results, pertain to offshore longline mussel farms in deep open ocean locations. However, if such farms rely on shore based operations for spat collection, the issue of habitat exclusion may need to be considered.
- A risk for pinnipeds interacting with mussel farm gear, aside from depredation to prevent predation, is injury or death due to entanglement, especially in vertical lines. However, pinnipeds do not seem to visit mussel farms and are thus, at low overall risk for interactions.
- Among cetaceans, the highest risk from mussel farms is to the baleen whales because they may have low ability to detect farms and to species (e.g., humpback whales) or individuals which roll when entangled. It is possible that tensioned anchor lines may cut into the skin and flesh of panicking animals, but this remains undocumented. Large animals with gaping mouths and extending flukes and fins may be at higher risk. Efforts undertaken by groups such as the Atlantic Large Whale Disentanglement Network (ALWDN) to remove large whales from active and derelict fishing gear could be expanded to include aquaculture interactions.
- Toothed whales are likely at less risk because their echolocating abilities may allow them to perceive the farm structures and avoid or navigate through them.
- Dolphins and porpoises echolocate, and their smaller size and agility may also lower risk of physical interactions with farm gear.
- Seabirds and sea turtles are at risk for interactions with and entanglement in farm gear. Some best management practices implemented for marine mammals may also benefit these species.
- Marine debris originating from aquaculture facilities poses risks for entanglement and ingestion, but the extent of the contribution of marine farms to the marine debris load has not been evaluated.
- There is non-lethal physiological risk that may occur due to exposure to ADDs.

Knowledge Gaps

There is still much to learn about how protected species are affected by all types of marine aquaculture. The following are priority knowledge gaps and research areas:

1. A formal risk analysis of potential aquaculture interactions and comparison to other marine activities such as fishing, shipping, boating, military operations, etc.
2. Quantifying the incidence of occurrence of protected species at aquaculture operations, and the result of their reaction to and interactions with associated gear
3. Long-term effects of non-lethal interactions with aquaculture gear, primarily ropes and lines
4. Species-specific differences in risk of harmful effects of aquaculture
5. Mortality rates for protected species directly attributable to marine aquaculture through entanglement or illegal killing
6. The extent and effects of habitat exclusion on resident and migrating populations of marine animals
7. Ecological impacts of behavioral changes, such as selective feeding at fish farms
8. Contribution of marine aquaculture to marine debris and resulting impacts
9. Benign technological solutions for excluding protected species from farms
10. Change in feeding ecology, nutrition and growth of animals foraging heavily at farms
11. Best Management Practices to reduce risk and avoid interactions

Options for Management

The following management options are proposed based upon the information in this report. These are consistent with recommendations by Clement (2013) and NOAA (Nash et al. 2005).

1. Site farms in areas which minimize the likelihood of overlap with the migration routes or critical breeding and feeding habitats of protected species. Locate farms away from haul out sites and rookeries.
2. Monitor regularly to detect the presence (and absence) of protected species at farms, document their behavior and any interactions with gear.
3. Train farm workers about legislation regarding interactions (no feeding, chasing, harassment, etc.) with protected species.
4. Keep all anchor and backbone lines properly tensioned.
5. Use predator nets if there is a chance that protected species are going to attempt to feed on cultured animals. This is primarily an option for smaller operations nearshore.
6. Dispose of all garbage and potential marine debris properly.
7. Purchase farm gear from aquaculture supply companies which offer products uniquely manufactured to allow the materials to be tracked back to specific farms. For example, rope designed with unique patterns can be used so that it can be identified (and quantified) as belonging to a certain farm if it is lost as marine debris.
8. Limit the use of underwater lighting.
9. Use caution when operating vessels around protected species.

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Northern gannet

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