2015 NOAA Marine Debris Program Report

Impact of “**Ghost Fishing**“ via Derelict Fishing Gear

March 2015

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Cover photo courtesy of the National Oceanic and Atmospheric Administration

For citation purposes, please use:
NOAA Marine Debris Program. 2015 Report on the impacts of "ghost fishing" via derelict fishing gear. Silver Spring, MD. 25 pp

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Acknowledgements

The National Oceanic and Atmospheric Administration (NOAA) Marine Debris Program would like to acknowledge Jennifer Maucher Fuquay (NOAA National Ocean Service, National Centers for Coastal Ocean Science) for conducting this research, and Courtney Arthur (NOAA National Ocean Service, Marine Debris Program) and Jason Paul Landrum (NOAA National Ocean Service, Marine Debris Program) for providing guidance and support throughout this process. Special thanks go to Ariana Sutton-Grier (NOAA National Ocean Science) and Peter Murphy (NOAA National Ocean Service, Marine Debris Program) for reviewing this paper and providing helpful comments. Special thanks also go to John Hayes (NOAA National Ocean Service, National Centers for Coastal Ocean Science) and Dianna Parker (NOAA National Ocean Science, Marine Debris Program) for a copy/edit review of this report and Leah L. Henry (NOAA National Ocean Science, Marine Debris Program) for design and layout. Funding for this project was provided by the NOAA Marine Debris Program.

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EXECUTIVE SUMMARY

"Ghost fishing" is a part of the global marine debris issue that impacts marine organisms and the environment. Lost or discarded fishing gear that is no longer under a fisherman's control becomes known as derelict fishing gear (DFG), and it can continue to trap and kill fish, crustaceans, marine mammals, sea turtles, and seabirds. The most common types of DFG to ghost fish are gillnets and crab pots/traps, with longlines and trawls less likely to do so. Ghost fishing can impose a variety of harmful impacts, including: the ability to kill target and non-target organisms, including endangered and protected species; causing damage to underwater habitats such as coral reefs and benthic fauna; and contributing to marine pollution. Factors that cause gear to become DFG include poor weather conditions, gear conflicts with other vessels or bottom topography, gear overuse, and too much gear being used.

Despite the major advancements of previous research toward our understanding of DFG and ghost fishing, detailed information on catch rates, mortality rates and the economic impacts of DFG is still scarce. Some areas have been intensively studied (e.g., Hawai'i), while others have little to no data available. There are numerous logistical and cost-prohibitive difficulties in executing ghost fishing research studies, and consistent units of measure are not used across studies, making comparisons difficult. Differences in international, national, and regional regulations and compliance are also problematic, in that catch limits, gear usage, gear type, sink times, and even attitude regarding proper gear use and disposal can vary widely geographically. Taken in the context of these differences around the world, more data are needed across wider geographical areas to better refine the impacts of ghost fishing that occur due to DFG.

This report is a summary of the current scientific knowledge of ghost fishing, the derelict fishing gear that contribute to it, the species mortalities, and the economic losses to certain fisheries due to ghost fishing mortalities. Gaps in knowledge are identified, and suggestions for the prevention and mitigation of DFG and possible future research foci are presented here within the framework of prevention, removal, and education as means of reducing ghost fishing. These three focus areas, however, should be considered together as a multi-pronged approach toward that goal.

The main conclusions for this summary paper are the following:

- Ghost fishing contributes to increased mortalities in a wide variety of marine organisms and is especially damaging to endangered and protected marine species, such as marine mammal and sea turtle populations. It remains difficult to determine accurate ghost fishing catch rates, and future efforts should focus on standardizing field methods and metrics.

- Economic impact studies show fisheries can be negatively affected by a variety of factors, including costs of replacing lost gear, costs of buying new gear to comply with new regulations, and decreased populations of target organisms due to mortality in DFG. Rates of gear loss are difficult to determine and have been calculated in a variety of ways in published studies, making direct comparisons within gear classes difficult with the current data, methods, and analyses. Standardization of methods and metrics would allow for comparable analyses to be done among fisheries and across different geographic areas, providing a more comprehensive and globally relevant view of the economic impacts of DFG.

- Multiple programs now exist to promote onshore collection, disposal, and recycling of used gear. Resources and outreach efforts, as well as initiatives to create better types of gear or methods of fishing, are needed to increase awareness of ghost fishing and how it fits into the much larger issue of marine debris. Improved relationships between industry, government and non-governmental organizations are also necessary to promote change and better management of DFG.

- Detailed information regarding ghost fishing and DFG (e.g., regulations, compliance rates, ghost catch rates, agency internal reports and published peer-reviewed literature) is not always easily accessible to interested parties. A central repository is suggested as a means of centralizing where information can be found on a variety of topics regarding DFG and ghost fishing. Having a central point of information could then be used to promote linkages between scientists, fisheries managers, regulatory agents, and the public. This could be a database, or series of databases, which could include: studies and projects completed and generalized results; direct links to those studies and projects for more detailed information; an interactive database in which fishermen or others can identify locations of DFG found and any associated animal mortalities; regulations for individual fisheries by state/region.

BACKGROUND

What is ghost fishing?

Ghost fishing refers to lost or abandoned fishing gear, also called derelict fishing gear (DFG), that continues to capture fish and other marine animals after the gear is no longer under the control of a fisherman (Smolowitz, Corps, and Center, 1978). The most common types of DFG to ghost fish are gillnets and crab pots/traps, but other types of fishing gear, like longlines and trawls, can also ghost fish if they become DFG. Although the original intent of each is to capture a particular "target" species, whether for commercial or recreational use, derelict fishing gear can continue to fish for target as well as non-target species (called ghost catch) after it is lost, broken, or discarded. For example, a crab trap may break loose from its buoy in bad weather and continue to trap crabs, which may then act as bait themselves and attract other fish or species not originally intended for capture. Ghost fishing specifically implies that the organisms caught in the DFG die as a result of starvation, predation, or cannibalism (Smolowitz et al., 1978). This means that just because an organism enters a piece of DFG, also known internationally as abandoned, lost or otherwise discarded fishing gear (ALDFG), the gear is not necessarily ghost fishing unless mortality occurs. The time over which DFG can continue to ghost fish can vary according to the specific gear type, but can range from days to years. Over the course of its lifespan, a piece of DFG may kill large numbers of commercially valuable or threatened species (Laist, 1987). This ghost fishing phenomenon is a part of the global marine debris issue that impacts marine organisms and the environment. Ghost fishing can impose a variety of harmful impacts, including: the ability to kill target and non-target organisms, including endangered and protected species; causing damage to underwater habitats, like coral reefs and benthic fauna; economic losses from target species mortalities and replacement costs; and contributing to marine pollution.

There are many ways that fishing gear can become derelict, and more than one of the following can be contributing factors:

1. Environmental: storms, wave action or currents, sedimentation, ice cover, deep-water conditions
2. Gear conflict: entanglement with other vessels or bottom topography such as reefs or rocky bottoms
3. Gear condition: breaks loose/cut loose (intent can be accidental or deliberate) due to old age/overuse;
4. Inappropriate disposal at sea

Early research into ghost fishing began in the 1970s (High, 1976; Pecci, 1978), shortly after the 1973 prohibition of abandonment or dumping of fishing gear by the International Maritime Organization Convention for the Prevention of the Pollution from Ships. Also during this time, construction of fishing gear transitioned from natural, biodegradable materials such as cotton and wood to plastic monofilament and vinyl-coated steel. Although these materials last longer, which is advantageous for the fishermen, they do not readily degrade and therefore prolong the potential for ghost fishing to occur, and they increase the total amount of marine debris overall as DFG.

Derelict fishing gear contributes to marine debris in general. Although it is impossible to get an accurate global number, a rough estimate is that less than 10% of marine debris by volume is DFG (Macfadyen, Huntington, and Cappell, 2009) and DFG is the main type of submerged marine debris (Macfadyen et al. 2009; Nagelkerken, Wiltjer, Debrot, and Pors, 2001; Chiappone, White, Swanson, and Miller, 2002; Sheridan, Hill, Matthews, G. Appledoorn, Kojis, and Matthews, T., 2005). A United Nations (UN) Food and Agriculture Organization (FAO) and UN Environment Programme (UNEP) report states that while most gear is not deliberately discarded, the problem of abandoned, lost and discarded fishing gear is getting worse due to the increased scale of global fishing operations and the above mentioned introduction of highly durable fishing gear made of long-lasting synthetic materials (Macfadyen et al., 2009). This suggests that the likelihood of ghost fishing may be increasing, although it is difficult to know exact numbers due to incomplete reporting of how much gear is actually lost and the difficulty in monitoring or retrieving DFG. Factors that contribute to the likelihood of DFG ghost fishing are the rates at which gear is lost, the catching efficiency of each specific gear type, and the species that are present in the area that may then be susceptible to ghost fishing (Brown and Macfadyen, 2007). Also not well-understood are the catch rates (how many organisms are caught) and mortality rates (how many organisms die) of species caught in DFG.

Despite previous research that increased our understanding of DFG and ghost fishing, detailed information on DFG based on the above factors is still relatively scarce, as few detailed studies have been done. Some areas have been intensively studied (e.g., Northwestern Hawaiian Islands), while others have little to no data available. There are numerous logistical difficulties in executing ghost fishing research studies, and consistent units of measure have not been used across studies, complicating comparison of results. Differences in international, national, and regional regulations and compliance are also problematic, in that catch limits, gear usage, gear type, sink times, and even attitude regarding proper gear use and disposal can vary widely geographically. Taken in the context of these differences around the world, more data are needed across wider geographical areas to better refine the impacts of ghost fishing that occur due to DFG.

This report is a summary of the current scientific knowledge of ghost fishing, the derelict fishing gear that mainly contribute to it, the species mortalities, and the economic losses to certain fisheries due to ghost fishing mortalities. Gaps in knowledge are identified, and suggestions for the prevention and mitigation of DFG and possible future research foci are presented within the framework of prevention, removal, and education as focus areas and means of reducing ghost fishing. These three focus areas, however, should be considered together as a multi-pronged approach toward that goal.

Ocurrence

Anywhere fishing gear is deployed, there is the potential risk for ghost fishing, and thus DFG can enter marine systems at a variety of locations worldwide. On this global scale, drifter experiments have shown five main areas where marine debris tends to accumulate which are known as convergence zones (Maximenko, Hafner, and Niiler, 2012). The ocean currents and prevailing winds concentrate water masses into these specific regions, and marine debris, including DFG, can likewise be concentrated there. One such "hot spot" of DFG accumulation with documented ghost fishing in the U.S. is the Northwestern Hawaiian Islands (NWHI). This hot spot is due to a concentration of ocean currents in an area known as the North Pacific subtropical convergence zone. DFG accumulated in this zone leads to the coasts and coral reefs of the islands, which has resulted in ghost fishing (Kubota, 1994; Donohue, Boland, Sramek, and Antonelis, 2001; Pichel, Veenstra, Churnside, Arabini, Friedman, Foley, Brainard, Kiefer, Ogle, and Clemente-Colon, 2003; Pichel, Churnside, Veenstra, Foley, Friedman, Brainard, Nicoll, Zheng, and Clemente-Colon, 2007). The DFG that are mostly responsible for ghost fishing in this area may originate from various current drift net fisheries from North Pacific Ocean fisheries, or may be decades-old remnants of Japanese, Korean, and Taiwanese fleets lost prior to high-seas drift net bans in the early 1990s (Donohue et al., 2001; National Marine Fisheries Service, 2007; Boland and Donohue, 2003). Since 1996, NOAA's National Marine Fisheries Service, NOAA's National Ocean Service, and other state and federal organizations have removed hundreds of tons of derelict nets from the NWHI's coral reefs in an effort to restore fragile habitats and reduce the impact on the local marine fauna (Pacific Islands Fisheries Science Center, 2012).

DFG released in the North Pacific Ocean represents only one area, albeit a very large area, where DFG accumulates and poses problems via ghost fishing. Other ocean basins, such as the South Pacific Ocean and the North Atlantic Ocean basins, also contain DFG, although these zones have not received as much attention in the literature as the North Pacific Ocean.

Additionally, as mentioned earlier, DFG can become a problem anywhere that fishing gear is deployed, including along coastlines. There are numerous other coastal regions and resources, like the Chesapeake Bay (Havens, Bilkovic, Stanhope, and Angstadt, 2011; Havens, Bilkovic, Stanhope, Angstadt, and Hershner, 2008), the Puget Sound (Pichel, et al., 2003; Good, June, Etnier, and Broadhurst, 2009; and Maselko, Bishop, and Murphy, 2013), and the Gulf of Mexico (Guillory, McMillen-Jackson, Hartman, Perry, Floyd, Wagner, and Graham, 2001), where both floating (e.g., gill nets, long lines) and fixed (e.g., crab traps/pots) fishing gear are lost and subsequently ghost fish for years. In these areas, the NOAA MDP has supported efforts to survey where DFG has been deposited in order to get a better sense as to where DFG occurs due to fishing activity in these areas. However, more work needs to be done to get a better sense of the overall extent of where DFG accumulates, both in the water column and on the sea floor.

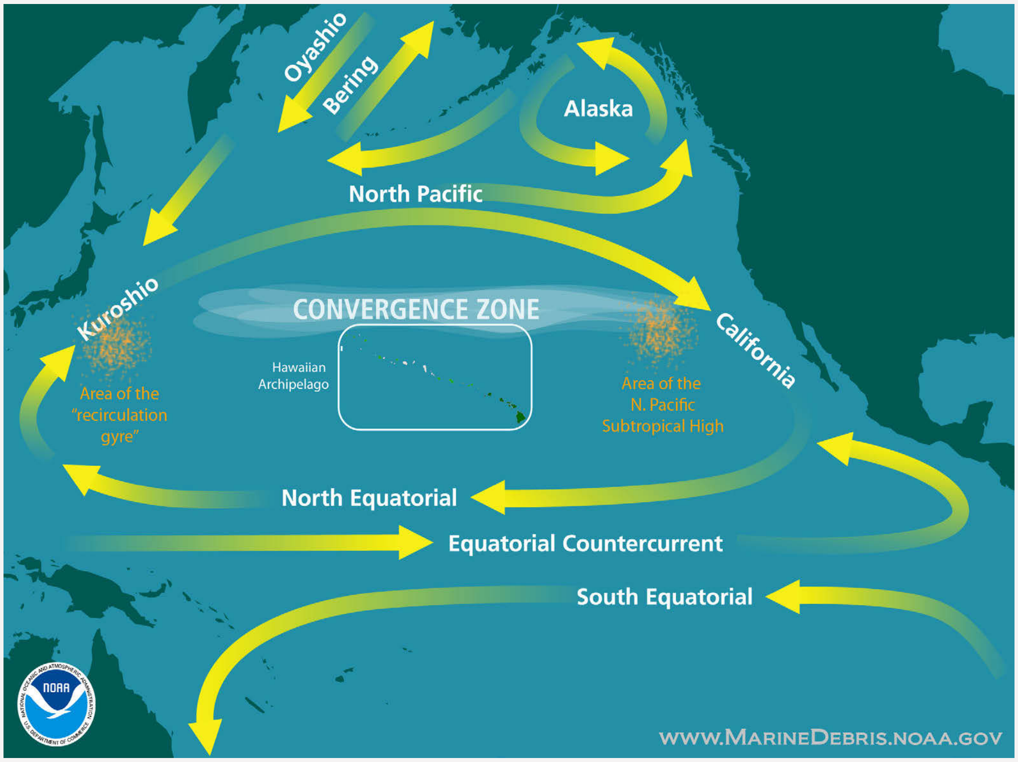

Figure 1. A map of the Eastern and Western Garbage patches. These regions have higher debris concentrations because of ocean circulation patterns. (Photo Credit: NOAA Marine Debris Program)

Impacts of Ghost Fishing

There are a wide variety of impacts that ghost fishing can have, including the DFG responsible for ghost fishing being a type of marine pollution, but three in particular stand out. Although the most obvious is the mortality of organisms in DFG, damage can also be done to the habitat in which DFG becomes lost, and economic losses are also a consequence of ghost fishing.

a recent study estimated there are **over 85,000 lobster and crab ghost traps** in the Florida Keys National Marine Sanctuary

Habitat

Fisheries operate in many different types of habitats in order to capture their target species, whether it is along the coast in shallow waters, or further offshore in open ocean (pelagic) areas. Coral reefs, like those in Hawaiʻi, are one type of habitat that can be impacted by ghost fishing, not only by the loss of organisms dying in DFG, but the physical damage done by the gear itself. This can occur when DFG such as lobster pots or bottom trawls sink or get dragged along the reefs by currents and storm action, which can destroy fragile corals and their associated inhabitants. Another habitat type that can be susceptible to impacts from DFG and ghost fishing is the benthos (Butterworth, Clegg, and Bass, 2012). These ocean bottom regions, although generally remote in location, can still be damaged significantly when DFG, especially trap gear, sinks to the bottom where it can smother organisms that live on top of and just below the sediments, like seagrasses, crabs, and worms.

Species Mortality

One of the most significant ghost fishing impacts of DFG is the unintended deaths of target and non-target species, which contribute to the overall depletion of populations. DFG that begins ghost fishing poses a threat to a variety of non-target fish (Stewart, and Yochem, 1987), turtles (Carr, 1987; Meager and Limpus, 2012), seabirds (Good, et al., 2009; Piatt and Nettleship, 1987), whales (Volgenau, Kraus, and Lien, 1995; Meager, Winter, Biddle, and Limpus, 2012), and seals (Boland and Donohue, 2003; Page, McKenzie, McIntosh, Baylis, Morrisey, Calvert, Haase, Berris, Dowie, Shaughnessy, and Goldsworthy, 2004). This is especially problematic when endangered or protected species including marine mammals and sea turtles die as a result of ghost fishing. Protected marine species have already declining populations that can be further set back by DFG. Even in non-endangered target species, mortalities due to ghost fishing can further deplete the population and lessen the sustainability of the fishery. One way ghost fishing is perpetuated is by the trapped and dead animals in the DFG acting as bait, attracting and potentially entrapping more organisms. For example, fish or crustaceans can enter a derelict lobster pot looking for food (which could be already trapped organisms) or shelter and may then become trapped themselves. To give an idea of the scale on which this could potentially occur, a recent study estimates there are over 85,000 lobster and crab ghost traps in the Florida Keys National Marine Sanctuary (Uhrin, Matthews, and Lewis, 2014). This suggests a definite risk for ghost fishing in just one region of the U.S. alone.

Economic

It is difficult to gauge accurate total costs associated with ghost fishing, as this varies across specific fisheries, and can depend on the gear type, weather, and ghost catch rates, among other factors. Questions that make calculating economic impacts difficult include:

- At what rate is trap gear lost annually?
- How long exactly can trap gear continue to ghost fish?
- How effective is the trap gear at ghost fishing?
- How is a value placed on the loss of both commercial AND non-commercial species?
- What are the costs of DFG on the environment?

For the fishers, their direct costs range from the money required to replace lost gear, to increased resources (i.e., fuel, ship time, more fishing gear, special equipment) needed to capture decreasing target fishery populations. This is especially problematic in deep-sea species that grow slowly (Merrett and Haedrich, 1997; Koslow, Boehlert, Gordon, Haedrich, Lorance, and Parin, 2000). If significant numbers of these animals are lost to ghost fishing, this further strains the sustainability of the population. Fishers also lose revenue from target organisms killed due to ghost fishing. Some studies estimate that over 90% of species caught in DFG are of commercial value (Al-Masroori, Al-Oufi, McIlwain, and McLean, 2004), which can contribute to a significant loss of revenue for fishermen. The economic impact of DFG is usually calculated either as the percentage of the catch that has commercial value in the region, or as a percentage of the commercial catch of the individual species caught. Some examples are a 1.46% loss of the commercial monkfish catch in northern Spain (Sancho, Puente, Bilbao, Gomez, and Arregi, 2003), a 4–5% loss of the commercial catch in the Baltic Sea (Tschernij and Larsson, 2003), and 20–30% of the Greenland halibut catch in Norway (Humborstad, Løkkeborg, Hareide, and Furevik, 2003), all attributed to ghost fishing (Ceccarelli, 2009). Another study in Washington state found early ghost fishing rates account for an estimated 4.5% loss in the Dungeness crab fishery per year, which equates to a harvest loss of over $744,000 (Antonelis, Huppert, Velasquez, and June, 2011).These examples show that the economic impacts of ghost fishing can be substantial, but they are specific to each fishery and area studied. And as with all the potential impacts of ghost fishing just mentioned, impacts will vary with the specific type of fishing gear in use.

The Gear

There are a variety of fisheries, usually categorized by what target species they are trying to catch specifically and by their scale of operation. Industrial and commercial fisheries operate on a broad scale requiring large boats and lots of gear (e.g., the Gulf of Mexico shrimp trawl fishery). Small-scale fisheries use smaller boats and less gear, like artisanal or recreational/sport fisheries. No matter what type of fishery it is, all run the risk of gear potentially becoming DFG. The types of DFG most often cited for ghost fishing are, in the order of prevalence and amount of available information (Shomura and Godfrey, 1990):

- Gillnets
- Pots/Traps
- Bottom trawl nets
- Longlines

Gillnets and pots have been the most documented gear types to date regarding ghost fishing, and this paper therefore concentrates on their loss rates, species mortalities, and mitigation efforts.

Figure 2. Several examples of different types of derelict fishing gear, from (a)gill nets, (b)to pots /traps, to (c) monofilament, to (d) trawl nets.
Photo credits: (a) US Fish and Wildlife Service, (b, c) Northwest Straits Foundation, (d) NOAA .

Gillnets

Gillnets are so named because the fish tend to swim through the mesh and get entangled by their gills, but they can also swim through mesh such that their bodies get wedged in the mesh or become snared by fins, teeth, or other body projections. Varying the mesh size of the net targets specific sizes of fish, and can be very selective for certain fisheries. There are many types of gillnets that can become DFG and therefore potentially ghost fish, but they mainly fall into two groups. Some are considered active gear as they are towed from a boat and then retrieved, as with trammel nets. Others are considered passive gear, like a drift net, as they are usually set in a particular location, then left unattended for a period of time, called "soak time," until retrieval. Although the specifics of how different types of gillnets are set vary, they are generally weighted at the bottom and have floats at the top edge so the net is oriented vertically in the water column. Passive gear can have soak times that last from hours to days depending on the fishery. This makes these passive types of gillnets more susceptible to becoming DFG and therefore more likely to ghost fish, as there is no person actively monitoring the net, as there is with active gear types (Kaiser, Bullimore, Newman, Lock, and Gilbert, 1996; Carr, Blott, and Caruso, 1992). The most common ways that gillnets become derelict are: breaking free from the floats; entanglement with the bottom surface, like reefs or rocky bottoms; and interaction or entanglement with other fishing gear present. This paper will primarily discuss gillnets as being the passive type, but other types may be referenced as well.

The ability for a gillnet to ghost fish depends on how open the net is as it drifts through the water column. Nets that "ball up" due to currents or tides tend not to be as effective, but those that have some open net surface remaining can continue capturing marine organisms to varying degrees (Erzini, Monteiro, Ribeiro, Santos, Gaspar, Monteiro, and Borges, 1997). Studies using experimental ghost nets suggest that as the net tangles and the open net area decreases, so does its ability to ghost fish (Kaiser et al. 1996; Carr et al. 1992; Revill and Dunlin, 2003). The likelihood of how well derelict gillnets can ghost fish can also vary with water depth. Those in shallower waters with more dynamic tidal and current conditions tend to ball up faster and stop fishing earlier, while gear lost or discarded in deep water with little tidal or current activity can continue to fish for years rather than months (Kaiser et al., 1996; Erzini et al., 1997).The monofilament construction allows for the nets to be nearly invisible in the water, thus making gillnets hard for fish and other marine organisms to see and avoid. The plastic monofilament does not degrade and, once discarded or lost, these nets can potentially continue to ghost fish for extended periods of time; some have been recovered actively ghost fishing after 20 years (Good, June, Etnier, and Broadhurst, 2010). The shape, size, and visibility of gillnets has an important bearing on how much gets caught (Ayaz, Acarli, Altinagac, Ozekinci, Kara, and Ozen, 2006), but nets generally decline in ghost catch rate with time (Brown and Macfadyen, 2007; FANTARED). Biofouling (the attachment and growth of other living organisms, such as algae) makes these nets more visible and thus easier to avoid with time, which ultimately decreases the catching ability of the net as well.

"Some studies estimate that **over 90% of species caught in DFG are of commercial value,** which can contribute to a significant loss of revenue for fishermen."

Gillnet Loss Frequency

There is little information regarding the frequency at which gillnets become DFG and the numbers of organisms lost due to ghost fishing. Early documented work on lost gillnets and ghost fishing began with Way (1977) describing finding fish and crabs in lost Newfoundland cod gillnets, and High (1981) demonstrating that derelict gill nets have the potential for causing major fish losses. The first comprehensive group of studies on DFG and ghost fishing consequences were the FANTARED studies, done between 1995–2005 and covering various parts of the United Kingdom, Norway, Sweden, Spain, France, and Portugal (Brown and Macfadyen, 2007). These studies, and others (Hareide, Garnes, Rihan, Mulligan, Tyndall, Clark, Connolly, Misund, McMullen, Furevik, Humborstad, Hoydal, and Blasdale, 2005; Brown, Macfadyen, Huntington, Magnus, and Tumilty, 2005), did include some gillnet loss rate data. Rates of static fishing gear loss in the European Union (EU) were found to be low, at <1% of all nets deployed each year, primarily due to high recovery rates of fishing vessels using GPS (Brown et al., 2005). One common factor found was the relationship between water depth and gillnet loss rates. Those nets used in coastal waters <200m are not considered to be a significant problem, while those used in deep waters >500m are most likely to be lost due to excessive net length, increased soak times and gear stress (Hareide et al., 2005). Deep-water fisheries in the northeast Atlantic were a noted exception to low gear losses, as they accounted for more than 25,000 nets of the total 33,038 reported lost (Brown et al., 2005). In addition to higher loss rates, the deep-water fish species present tend to be slow growing, long lived, and have low reproductive rates (Merrett and Haedrich, 1997; Koslow et al., 2000). These traits make such species highly vulnerable if ghost fishing significantly impacts population numbers.

Table 1. Summary of gillnet loss/abandonment/discard indicators from around the world

Region	Fishery/gear type	Indicator of gear loss (data source)	Data source
North Sea & NE Atlantic	Bottom-set gill nets	0.02–0.09% nets lost per boat per year	EC contract FAIR-PL98-4338 (2003)
English Channel & North Sea (France)	Gillnets	0.2% (sole & plaice) to 2.11% (sea bass) nets lost per boat per year	EC contract FAIR-PL98-4338 (2003)
NE Atlantic*	Deepwater monk fish and shark fisheries	>25,000 nets; 1,254 km sheet netting per year	Hairede et al., 2005
	Deepwater Greenland halibut	0.14–0.17% nets per season; est. 15 nets per day	DeepNet 2009
Mediterranean	Gillnets	0.05% (inshore hake) to 3.2% (sea bream) nets lost per boat per year	EC contract FAIR-PL98-4338 (2003)
Baltic Sea*	Gillnets	5,500–10,000 nets lost per year	Baltic Sea 2020 Foundation
North Pacific*	Gillnets	7,000 km of net per year	Bullimore et al., 2000
NW Atlantic	Newfoundland cod gillnet fishery	5,000 nets per year	Breen, 1990
	Canadian Atlantic gillnet fisheries	2% nets lost per boat per year	Chopin et al., 1995
Caribbean	Nets	79% of nets	Matthews and Glazer, 2010

(Adapted from Macfadyen et al. 2009)

Even if high recovery rates are reported, DFG still exists. For example, Macfadyen et al. (2009) noted that despite a reported lost net recovery rate between 80–100% in most Norwegian fisheries, there were still 6,759 derelict gillnets picked up from Norwegian waters by various retrieval programs, which indicates the continued need for these types of programs as unreported net losses apparently still occur. Other published data on gillnet losses exist for various parts of the world, as summarized in the table adapted from Macfadyen et al. (2009) below. One thing to note is the inconsistency between how these losses are reported. More studies need to be done not only to get an accurate assessment of gillnet loss rates, but should be done using standardized measurements in order to make more direct comparisons between them.

Differences in local fishing practices and attitudes also contribute to the wide variability in gear loss. For example, Matthews and Glazer (2010) noted that nets made up a small percentage of the type of fisheries gear used (about 24% of all gear was nets), but of those nets there was a loss rate of 79%. Of the Caribbean fisheries surveyed, 24% listed "apathy" as to why gear was lost, abandoned, or discarded in addition to the most frequently cited reason of bad weather. Conversely, Matsuoka, Nakashima, and Nagasawa (2005) found that Filipino coastal fishermen avoided gillnetting around coral reefs and dove to retrieve lost nets, as gillnets are expensive assets for small-holder fishermen in developing countries. He goes on to suggest that the magnitude of the ghost fishing problems may depend on the socioeconomic status of fishing sectors in each country.

Gillnet Mortalities

Ghost fishing by gillnets has an impact on a wide variety of marine life—from fish to sea birds and mammals to benthic organisms—with some of the greatest impacts on turtles (Roeger, Munungurr, and Wise, 2004; Leitch, 2001). The threat to marine turtles posed by derelict nets is thought to equal fishing efforts before the introduction of turtle excluder devices (TEDs) (Kiessling, 2003). Although target species are affected as well, ghost fishing is especially problematic when it causes mortality of protected species. Critically endangered Hawaiian monk seals have been found entangled in masses of monofilament driftnet with seven confirmed deaths (Donohue, 2001; National Marine Fisheries Service, 2007; Henderson, 1984). Considering that there are approximately only 1,200 animals left in this critically endangered species, DFG entanglement has been deemed one of four serious threats to the population (NMFS, 2007). Approximately 25% of reported cetacean entanglements in Australia occurred in derelict fishing nets (Ceccarelli, 2009). Two Indo-Pacific humpback dolphins and three Australian snubfin dolphins, both "near threatened" species, were reported to have drowned in nets in the Australian Shark Control Program between 2008 and 2011, and in Cape Arnhem, northern Australia, 29 dead sea turtles, all seven species of which are either endangered or threatened, were found in ghost fishing nets over a four-month period (Meager et al., 2012).

There are still very few controlled experiments that focus specifically on determining gillnet ghost fishing mortalities and how long they can effectively still capture organisms once they become DFG. One study by Kaiser et al. (1996) used a fixed gillnet set (one gillnet and one trammel net) left offshore of the UK and allowed them to soak and ghost fish for 9 months. In total, the gillnet caught 226 fish after 70 days and 839 crustaceans after 136 days, and the trammel net caught 78 fish after 22 days and 754 crustaceans after 136 days. Although damaged by storms, the lost nets continued to catch commercial crustacean species for the nine months of the study, and is suggestive that ghost fishing could have continued for longer (Kaiser et al., 1996). In another DFG "hot spot" in Puget Sound, WA, a comprehensive analysis quantified the mortality of all marine organisms recovered from 870 derelict gillnets found and included (Good et al., 2010):

- 960 marine fishes (22 species)
- 509 marine birds (15 species)
- 23 marine mammals (4 species)
- 65 species of marine invertebrates

Studies about similar gear types can give seemingly contradictory results if all of the study parameters are not the same. For example, unaccounted mortality caused by gillnet ghost fishing was considered unimportant in UK coastal waters (Revill and Dunlin, 2003) and in the hake, *Merluccius merluccius*, fishery off the Algarve region of Portugal (Santos, Saldanha, Gaspar, and Monteiro, 2003), but this may be due to the small number of nets tested. On the other hand, ghost fishing by lost gillnets was considered to be important for the Greenland halibut, *Reinhardtius hippoglossoides*, on the Norwegian continental slope (Humborstad et al., 2003) and for the cod, *Gadus morhua*, in the Baltic Sea (Tschernij and Larsson, 2003). However these latter results are from deep-water fisheries where water depth is a large contributing factor to gear loss and therefore ghost fishing. These seemingly conflicting results emphasize both, the need for more comprehensive studies, as well as some standardization of methods and how results are reported.

Figure 3. Fishermen removing bycatch from recovered gillnet at sea. (Photo Credit: NOAA)

Derelict Gillnet Impact Mitigation

Efforts have been made to reduce the impact gillnets have on fisheries populations and loss of non-target species via by-catch, as well as their contributions toward marine debris in general. The EU banned the use of driftnets over 2.5 kilometers long in 1991, and the United Nations followed up with a ban in all international waters in 1992. The EU Council Regulation (EC) management measures were revised in 2006 and now include a permanent ban on all deep-water gillnet fisheries at depths >600 m and impose maximum limits on the length of nets deployed and the soak time in the remaining fisheries at depths <600 m (Council Regulation (EC) No. 41/2006).

In the U.S., gillnet fisheries generally require licensing and are mainly regulated based on mesh size and length, soak time, and area. But rules for gillnet fisheries can vary from state to state and even within a state. In Hawai'i, each island has different or no regulations on the use of a type of gillnet called lay nets (National Marine Fisheries Service, 2010). Florida recently halted enforcement of a 1994 state constitutional amendment limiting gillnet fishing in state coastal waters. And tribal versus state laws can vary within a state, as in Oregon and Washington states, regarding gillnet use in the Columbia River (Washington Department of Fish and Wildlife, 2013). In Oregon, gillnets are allowed for use only on the Columbia River and there is a ban on gillnetting for steelhead. This ban does not affect tribal fisheries, which are allowed to use set nets. As of 2012 it is now mandatory for commercial fishermen to report lost nets to the Washington State Department of Fish and Wildlife within 24 hours of loss.

Longlines and Trawls

Data on ghost fishing mortality and gear loss for derelict bottom trawl, longline, jigging, and fish weir gears are minimal in comparison to gillnets and trap gears (Brown et al., 2005; International Council for the Exploration of the Sea (ICES), 2000; Tasker, Camphuysen, Cooper, Garthe, Montevecchi, and Blaber, 2000) . However, there is some limited documentation of derelict longlines being able to ghost fish, although mortality rates tend to be low (ICES, 2000; Huse, Løkkeborg, and Soldal, 2000). Longlines are submerged lines with baited hooks set at intervals and can be up to 50 miles long. Longlines can be set to fish near the surface (in pelagic waters) to catch fish like tuna and swordfish, or laid on the seafloor (demersal) to catch deep-dwelling fish like cod and halibut. Many lines, however, can hook sea turtles, sharks, and seabirds that are also attracted to the bait. Impact data collected to date suggest that seabirds tend to be the most susceptible to longlines (Tasker et al., 2000). Between 2004 and 2013, observed shallow and deep-set longlines in Hawai'i had 652 seabird mortalities compared to 72 sea turtle deaths and 21 marine mammal deaths (NOAA Fisheries-Pacific Islands Region reports). Although these data are from active gear and not DFG, it implies that when longlines become derelict, they could most likely continue to cause mortalities due to entanglement and hooking. Pilot whales have been observed to interact with fishery operations, and between 1992 and 2008, five pilot whale mortalities were attributed to the pelagic longline fishery along the U.S. Atlantic coast, although again these data are from observed longlines that are actively fishing and not necessarily from DFG (National Marine Fisheries Service, 2012). Along the coast of British Columbia, marine mammals known to become entangled in longlines are the harbor porpoise, Dall's porpoise, Pacific white-sided dolphin, minke whale, humpback whale, fin whale, and orca (Williams, Ashe, and O'Hara, 2011).

Efforts to mitigate derelict longline gear impacts have been limited, although methods such as setting lines at night versus daytime and using deterrents such as streamers during line setting have been suggested (Brothers, Cooper, and Løkkeborg, 1999). In addition, the winner of the 2011 World Wildlife Fund (WWF) Smart Gear contest developed a double-weighted mechanism for using longlines that reduced bird by-catch by 89%, with no effect on target fish catch rates.

Various types of trawls (beam and otter) are used for various fisheries, but all are considered active types of fishing, as they are usually pulled behind a boat. Trawls can ghost fish if they break free from the ship, either through gear fatigue or snagging on bottom features like rocks, and stay stretched open. However, little attention has been given to this gear type in the context of ghost fishing (Shomura and Godfrey, 1990).

Trap Gear

Pots and traps (hereafter referred to as trap gear) are considered passive gear types that entice target species and ultimately entrap them. (Food and Agriculture Organization, 2001). Trap gear have lines attached to buoys at the surface for retrieval, and can be set either individually or in multiple sets of trap gear linked together by groundlines. Similarly to nets, the specificity of what is caught can vary depending on characteristics of the trap gear itself. The size and configuration of the opening sets the size of the largest organism that can get inside the trap gear, and the sides determine the minimum size that can remain trapped inside. The shape of trap gear can also help dictate what is being targeted. Trap gear have doors or escape panels that are usually fastened shut by a cord of twine or some other biodegradable material, so in the event it does become derelict, the cord will ideally rot and allow the door to open, releasing any trapped animals. In the past, trap gear frames used to be made of wood, but now tend to be metal or coated with a plastic resin. This makes the trap gear much sturdier and longer lasting, which is beneficial to the fishermen, but also puts lost gear at higher risk of being able to ghost fish for longer periods if not retrieved. As with gillnets, water depth can be a factor in how effectively trap gear can ghost fish. Deep-water pots, which are less damaged by waves and storms and less fouled by organisms, may continue to ghost fish for longer time periods than those in shallow waters (Matsuoka et al., 2005).

Trap Gear Loss Frequency

Data are relatively scarce on the loss rates of derelict trap gear, and vary by region and specific fishery. In areas of the EU, studies tend to show relatively low overall loss rates, and trap gear are considered to have little impact on ghost fishing overall (Brown et al., 2005). For example, in the Algarve region of southern Portugal, more than 700 octopus traps were lost, but had medium to high recovery rates to offset these losses (FANTARED 2, 2003). However, the area in which trap gear is deployed can also be a factor in loss rates, as retrieval of DFG tends to be less difficult in shallow, coastal waters compared to deeper waters, or places where currents are especially strong. Strong currents account for >50% of shrimp pot losses each year throughout the Puget Sound and Hood Canal according to one study (Natural Resources Consultants, 2012).

One way to track loss rates for trap gear is by their registration tags or licenses. In the U.S., most states require licenses for trap gear, so records exist for how many have been requested, but determining the actual amount of gear that becomes derelict is still not well documented. The Maine Department of Marine Resources receives over 3 million license requests per year, and from 2009 to 2011 it also received about 38,000 requests for lobster trap replacement licenses per year (Johnson, 2012), which implies that a similar amount of gear was either lost or stolen, with no differentiation between the two. Other published data on trap gear losses exist for various parts of the world, as summarized in the table below, also adapted from Macfadyen et al. (2009).

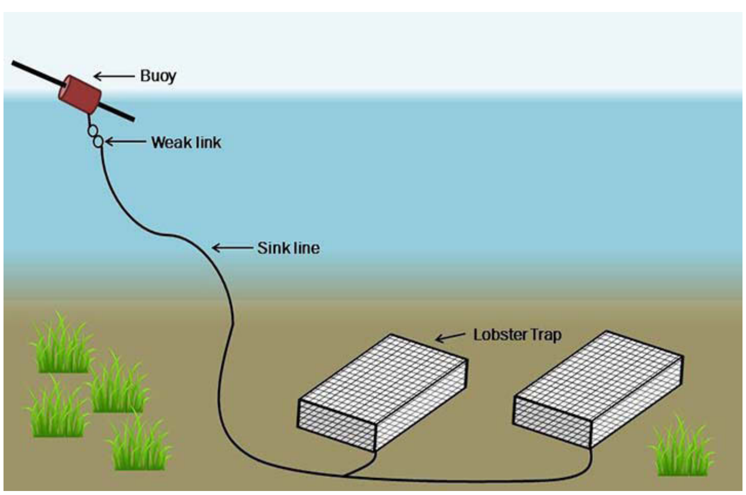

Figure 4. The basic configuration of lobster trap deployment. (Diagram Credit: NOAA)

Trap Gear Mortalities

A variety of marine organisms, both target and non-target species can fall victim to ghost fishing via trap gear. Approximately 250,000 derelict traps are added each year in the Gulf of Mexico (Guillory et al., 2001), resulting in the loss of more than 250,000 blue crabs per year in Louisiana alone. A single crab pot in the Chesapeake Bay was estimated to have a potential ghost catch rate of 50 blue crabs per crab pot (Havens et al., 2008). In southeast Alaska, a different region where crab traps can also be a nuisance for the Dungeness crab fishery, a recent study showed that in selected bays during summer closures in 2009 and 2010, 123 pots containing 215 Alaskan Dungeness crabs were found (Maselko et al., 2013). The study also estimated that these pots could last for an estimated maximum ghost fishing time that exceeds seven years, a long-term problem for this fishery. The potential for long time periods when trap gear can ghost fish, especially given the fact that trap gear can be "self-baiting," just compounds the problem. A one-year, Washington Department of Fish and Wildlife survey of derelict shrimp pots found that pots could potentially capture 3,796 to 7,580 endangered species of rockfish per year (Natural Resources Consultants, 2012). Other documented cases of ghost fishing involving endangered species have occurred with trap gear, including sea turtles found in derelict pots or their associated float lines in Queensland, Australia (Meager and Limpus, 2012) and four fur seal pups drowned in a rock lobster pot in New Zealand (Page et al., 2004). Johnson et al. (2005) studied the entanglements of 31 right whales and 30 humpback whales to assess the types and parts of fishing gear most likely to entangle these animals and found 81% involved entanglements in buoy lines or groundlines from pots, but could not distinguish whether this gear was ghost fishing at the time of entanglement or was being actively fished at the time of entanglement (Johnson, Salvador, Kenney, Robbins, Kraus, Landry, and Clapham, 2005). As with gillnets, there is still much more research to be done in order to more accurately gauge the extent of welfare impacts and mortalities due to trap gear ghost fishing.

Derelict Trap Gear Impact Mitigation

Advancements are being made in technologies to reduce the likelihood of derelict trap gear being able to ghost fish. The shape of the trap can be important in determining catch rates, with some experimental conical shaped traps having lower catch rates for sub-sized crabs than rectangular traps (Hébert, Miron, Moriyasu, Vienneau, and DeGrace, 2001). Cull rings are required to be included in the design of crab pots in order to allow undersized crabs to escape. Biodegradable release cords (rot cords) are also mandated in trap gear to allow trap panels to eventually open should the trap become derelict and thus reduce ghost fishing ability and duration. For example, the estimated Dungeness crab trap ghost fishing duration was 126 days for traps with escape cord and 2.2 years for traps without escape cord, but the effectiveness of the rot cords (i.e., degradation rate) depends on various environmental factors influencing the degradation rate of the cord (e.g., water temperature, fouling organisms, etc.) (Antonelis et al., 2011). Current research is investigating the use of completely biodegradable escape panels (Bilkovic, Havens, Stanhope, and Angstadt, 2012). Even with the required use of biodegradable escape panels and release cords, the trap gear can become biofouled with algae and encrusting animals like barnacles to the point that the escape mechanisms don't always release sufficiently to allow animals to escape. A 2010 Massachusetts Division of Marine Fisheries study deployed 18 lobster pots with biodegradable escape panels in Cape Cod Bay and Buzzards Bay, and found that more than half of those pots continued to catch lobsters and other organisms long after the escape panels were set to degrade to the point where animals should have been able to escape (Lyons, 2012).

Regulations that exist regarding trap gear can vary widely from nation to nation and from state to state, but many are banning certain types of trap gear to decrease losses from ghost fishing and reduce marine pollution via DFG. The state of Florida prohibited the use of fish traps in state waters in 1980 following by-catch and ghost fishing concerns (Newman et al., 2011). There is currently a motion, put forward by the International Coral Reef Initiative (ICRI) in Oct 2013, to ban fish traps in the Caribbean. In 2007, Massachusetts became the first state to require year-round use of sinking groundline in all state waters to reduce the risk of whale entanglement in the lines connecting lobster pots (Massachusetts Department of Fish and Game, 2015). This is now a federal requirement throughout the entire fishery. In the Gulf of Mexico, the Gulf Council banned placing new fish traps in 1987 and phased out existing traps over a 10-year period. The South Atlantic Fishery Council outlawed fish traps in 1988, banning them in the ocean's federal waters three miles off the coast between North Carolina and Florida. One exception to the ban is for small traps for black sea bass, mainly off the Carolinas. And although regulation efforts are on the books, it is still difficult to know how well they are being enforced or if fishers are in compliance.

Table 2. Summary of trap gear loss/abandonment/discard indicators from around the world

Region	Fishery/gear type	Indicator of gear loss (data source)	Data source
Gulf of Aden	Traps	c. 20% lost per boat per year	Al-Masroori, 2002
ROPME Sea Area (UAE)	Traps	260,000 lost per year in 2002	Gary Morgan, personal communication, 2007
Australia (Queensland)	Blue swimmer crab trap fishery	35 traps lost per boat per year	McKauge, undated
NE Pacific	Bristol Bay king crab trap fishery	7,000 to 31,000 traps lost in the fishery per year	Stevens, 1996; Paul et al.; 1994; Kruse and Kimker, 1993
North Pacific*	Traps	7,000– 31,600 pots per year	Bullimore et al., 2000
NW Atlantic	New England lobster fishery	20– 30% traps lost per boat per year	Smolowitz, 1978
	Chesapeake Bay	Up to 30% traps lost per year, mainly in the hurricane season	NOAA Chesapeake Bay Office, 2007
Caribbean	Guadeloupe trap fishery	20,000 traps lost per year, mainly in the hurricane season	Burke and Maidens, 2004

(Adapted from Macfadyen et al. 2009)

THE FUTURE

Ghost fishing by DFG is one part of the overall marine debris issue that impacts the habitats and species of our oceans. More information has become available on this specific topic in recent years, as evidenced by the increasing research literature, as well as the efforts of independent organizations such as GhostNets Australia and Ghostfishing.org in promoting awareness and providing educational resources. Previous comprehensive studies by the Institute for European Environmental Policy (Brown et al., 2005) and Food and Agriculture Organization (Macfadyen et al., 2009) have provided detailed recommendations for the reduction of ghost fishing by lost or abandoned gear, with a general consensus that prevention is the best means to address this issue. Given the complexity of factors that contribute to DFG, a multi-pronged approach is needed to: address prevention of the introduction of new DFG and therefore prevention of eventual ghost fishing; use cost effective detection and removal mechanisms to address already present DFG; and increase education and outreach programs to promote awareness of DFG and ghost fishing. Taken together, these actions, as suggested below, would provide the most comprehensive and collaborative approach to mitigate the presence and impact of ghost fishing derelict fishing gear in the world's oceans.

Prevention

Preventive measures would reduce the likelihood that fishermen will discard gear at sea and make gear less likely to ghost fish and could include:

1-Improvement of gear design to reduce likelihood of failure or snagging.
2-Spatial zoning of fisheries to avoid gear conflict and increase navigational awareness of gear in water.
3-Reduced fishing effort (lower soak times, limiting fishing time, less gear per boat).
4-Reducing ghost fishing efficiency of gear (improve biodegradable aspects for release or disabling of lost gear over time).
5-Gear marking, integrated GPS to allow for immediate recovery, port or state monitoring, and inspection of gear.
6-Provide affordable port disposal facilities and incentives to discourage improper disposal at sea.

Many preventive mechanisms are already being implemented in various ways. Gear improvements such as the use of integrated GPS tags are already widely used in EU fisheries (Macfadyen et al., 2009) and account for the higher documented recovery rates (FANTARED 2). A new type of completely biodegradable escape panel for crab pots has been developed from polyhydroxyalkanoates, or PHAs, in which the entire escape panel degrades rather than just a cord (Bilkovic et al., 2012). Cooperation between lobstermen and rope manufacturers led to new groundline improvements to reduce chafing and breakage of the lines on rocky bottoms, thus reducing the likelihood of trap gear becoming DFG (Schreiber, 2011). For example, a NOAA-sponsored grant supported a Gulf of Maine Lobster Foundation project, The Bottom Line, which allowed for rope exchanges from the lighter sink lines to more durable lines for groundlines, and then recycled or re-used the old line to make a variety of items, from plastic pots to doormats (Gulf of Maine Lobster Foundation, 2015).

The cost of disposing fishing gear properly can be high, so in some cases it is dumped at sea as a low cost disposal method (Pooley, 2000). The need for affordable port reception facilities and incentives for bringing DFG back to shore for disposal is vital to the prevention of marine debris and DFG (Carswell, McElwee, and Morison, 2011). One example of a successful incentive program is the "Waste Fishing Gear Buy-Back" project, implemented in the Republic of Korea since 2003, which provides disposal bags for fishermen, who receive about US$10 per 100-liter bag upon their return (Macfadyen et al., 2009). Similar incentive-type programs should be expanded in other regions when possible to reduce improper disposal at sea. But even with incentives, there must still be affordable disposal facilities available once waste is brought back to shore.

Removal

A number of programs specifically aimed at the removal of DFG have appeared in the past decade and have successfully removed DFG, onshore and at sea, thereby decreasing the potential for ghost fishing. Several of these are shown in table 3, with the amount of DFG each recovered.

Clean up programs do incur costs. One calculation for the cleanup of DFG in the Republic of Korea had an average clean-up cost of US $1,300 per ton over a six-year period (Hwang and Ko, 2007), which is cost effective compared to one 2004 effort in the NWHI that averaged US $25,000 per ton (Raaymakers, 2007). Funding for these programs is not always consistently available, making it difficult for many nations to reduce the concentration of marine debris in the marine environment through removal efforts alone. For example, GhostNets Australia receives some funding from national and state governments, as well as relying on matches by stakeholder's cash and in-kind contributions, sponsorships and donations(Arafura Times, 2012). Conversely, the California Lost Fishing Gear Recovery project is entirely funded by grants. By increasing partnerships between government organizations, non-governmental organizations (NGOs), and the communities they serve, funding for such programs does not necessarily become the burden of a single entity, and the improved working relationships between such groups can increase global participation. The Gear Grab organization, part of the Gulf of Maine Lobster Foundation, is such an example, where lobstermen, scientists, and the local communities work together to make the fishery sustainable, including efforts to reduce ghost fishing.
One creative removal program is the Louisiana Sea Grant's derelict crab trap "rodeo," which since 2004 has enlisted volunteers to collect more than 20,000 derelict traps during the annual 10-day fishery closure (Louisiana Sea Grant, 2015). Smaller, shorter-term programs also exist. From 2009 to 2011, the Monterey Bay National Marine Sanctuary and its partners implemented the Lost Fishing Gear Removal project to document and

Table 3. Total derelict fishing gear removed as a direct result of removal efforts in specific geographical areas:

Time Frame	Gear Amount Recovered	Project/source	Geographical Area
1996–2014	820 metric tons of DFG(and other marine debris)	NOAA's Pacific Islands Fisheries Science Center	Papahānaumokuākea MNM
2006–2012	60+ tons removed	CA lost fishing gear recovery project	Coastal California
2004–2012	12,000+ nets	GhostNets Australia	Australia
2008–2013	161 nets; 28934 crab pots; 4,202 other pots	CCRM VIMS	Chesapeake Bay, US
2000–2006	10,285 tons	Korean coastal cleanup campaigns (Hwang and Ko, 2007)	Korea
	20 tons fishing nets	Healthy Seas Initiative	North Sea, Adriatic Sea, Mediterranean Sea
	5,600 traps	Gear Grab.org	Gulf of Maine

remove lost fishing gear from the deep-water habitats of the sanctuary using a remotely operated vehicle, the Phantom HD2. Retrieved gear included over 1,000 feet of rockfish gillnet, a variety of crab and spot prawn traps, and 700 pounds of clump weight lead (Monterey Bay National Marine Sanctuary, 2014).

Another mechanism to increase retrieval is to improve the detection of gear once it is lost or abandoned. Ghost gear that washes ashore is relatively straightforward and easy to identify. What is more difficult to locate and retrieve is ghost gear that is offshore, especially in deep water. Modeling, an indirect method, can help predict where DFG may be accumulating based on ocean currents and wind patterns and better target specific areas for monitoring and removal programs. One example of this is the Debris Estimated Likelihood Index (DELI), which uses correlations between sea surface temperatures and chlorophyll levels to successfully predict areas of marine debris accumulation in the North Pacific (Pichel et al., 2007). Other technologies can be added in conjunction with modeling, such as remote sensing via satellites or aircraft to direct ship-based recovery efforts (McElwee, Donohue, Courtney, Morishige, and Rivera-Vicente, 2012). Although radar has generally been shown to be limited in application for debris detection, since debris generally does not provide a clear target profile for a radar return, a multi-pronged approach has been used by programs such as GhostNet Australia, NAVSAE, and GEOSS (Mace, 2012). One study in the U.S. used side scan sonar and a submersible vehicle to find derelict Tanner crab pots off Alaska and estimate ghost fishing catch rates (Stevens, Vining, Byersdorfer, and Donaldson, 2000). Side scan sonar has also been used in surveys to locate DFG in the Chesapeake Bay and the U.S. Virgin Islands (Clark, Pittman, Battista, and Caldow, 2012).

The removal of DFG is only one part of the solution. The reuse or recycling efforts of retrieved DFG now being launched are crucial to diminishing further environmental impacts due to landfill disposal or incineration, as well as disposal at sea. One such program is the Healthy Sea Initiative, which has taken more than 20 tons of discarded nets from the North, Adriatic, and Mediterranean Seas that will be recycled into ECONYL® yarn, used in clothing, carpet, and tiles (Ghostfishing.org, 2013). Another is the Fishing for Energy program, through which "commercial fishermen are provided with no-cost opportunities to dispose of old and unused fishing gear," which is then converted to electricity that can be used downstream. The program is a nationwide partnership between Covanta Energy, the National Fish and Wildlife Foundation, the NOAA Marine Debris Program, and Schnitzer Steel Industries, Inc. As of February 2015, over 2.8 million pounds of fishing gear has been collected at 42 ports in 10 states through this program. Another creative approach to recycling DFG is the Ghost Nets: Creative Collaborations exhibit, begun in 2004, which displays indigenous community artwork made from DFG recovered by the GhostNet Australia program.

Education and Outreach

One of the most common recommendations in the published literature is to increase outreach and education programs as means to help prevent the accumulation of DFG, and a variety of these programs already exist. NOAA and the Ocean Conservancy collaborated to create the Keep the Coast Clear Campaign, which is a targeted public awareness and education campaign to help with the understanding of marine debris impacts on ocean health with the goal of engaging people to prevent and eliminate marine debris.

Ghostfishing.org is a non-profit organization of divers that "collects, motivates, and initiates ghost fishing projects around the world" to increase awareness in the global diving community, and provides links to worldwide collaborations for the removal and recycling of DFG. But other types of outreach can also be applied to more directly engage fishermen, especially in industries that become affected by closures or decreased catch limits, so that they can become part of the management solution and promote sustainability for their future efforts.

One example of this is the Marine Debris Location and Removal Program in Virginia, in which watermen affected by the crab dredge fishery closure were compensated for income loss by participating in a project to retrieve ghost pots and nets (VIMS, 2015). They were trained in proper retrieval techniques and between 2008–2012 removed over 38,000 pots from the Chesapeake Bay that contained over 32,000 organisms (VIMS, 2015) from 40 species of crustaceans, fish, birds, whelk, and terrapins (Havens et al., 2011). Information from this project has also been turned into a lesson plan for grades 6–12 (Petrone, 2015), which allows student to use real world data and increases student awareness of ghost fishing.

Outreach and education must also extend beyond schoolhouse curricula to include policy makers, port authorities, and fishery managers. The NOAA Marine Debris Program continues to expand its outreach to provide information regarding all aspects of marine debris, including ghost fishing, with their growing clearinghouse of information as part of Marine Debris Act (2012).

One major gap in this area is the lack of web accessible data products regarding ghost fishing information, studies, and projects. Some databases already exist such as StrandNet, an Oracle database, which summarizes all records of sick, injured, or dead marine wildlife reported to the Department of Environment and Heritage Protection in Queensland, Australian (Department of Environment and Heritage Protection, 2014). This is a powerful tool that centralizes data from known mortalities as compiled by five different agencies across the country, including those from derelict fishing gear. Having a centralized location with one or more searchable databases would be a significant advancement for educational and outreach purposes, not just locally but globally. There would be a need to have mechanisms in place to oversee management, verification, and distribution of such data.

Suggestions for data to include are:

- Spatial zoning of fishing gear regulations searchable by state/region/nation/fishery
- Mortality of organisms searchable by species/region found
- Location of found DFG with data provided by fishermen, scientists, and general public
- List of projects/initiatives from both governmental and non-governmental organizations to promote collaborations and reduction of duplicative research efforts
- Published literature, including government reports, conference summaries, and links to peer reviewed literature

There must be reliable, comparable scientific data generated in the first place before it can be incorporated into education and outreach programs. Although the body of data is increasing regarding ghost fishing and DFG, much remains to be studied, especially regarding economic losses, species mortalities, and gear loss rates.

It is inherently challenging to study the complex factors briefly mentioned in this review paper that contribute to ghost fishing, but it is necessary to promote accurate understanding of these factors and the role each contributes to ghost fishing. Experimental design is critical. Studies should be done in the same regions under the same environmental conditions with commercial and recreational gear, with similar numbers of gears set. Monitoring of artificial ghost gear should be done regularly in situ, and the reported data should be in similar units of measure so that results are more directly comparable across industries and geography.

Summary & Recommendation

Ghost fishing is clearly a global issue, and although the volume of literature on the subject is increasing, much is still unknown regarding the exact number of mortalities, and the extent of its environmental and economic impacts. The implementation of large-scale studies and long-term monitoring programs as a means to increase our knowledge on specific topics—such as DFG loss rates, fishery economic losses due to ghost fishing, etc.—has been suggested often and with good cause, as much is still to be learned regarding the impacts of ghost fishing. More studies need to be conducted to increase the data available on the concentration and distribution of DFG, the economic impacts of ghost fishing, and the best ways to mitigate what DFG already exists.

A continued emphasis on the prevention of gear loss is considered to be the most critical advancement necessary to help mitigate all ghost fishing impacts, and the effort must be global and sustainable. New collaborations between government agencies, NGOs, and private industries and organizations are essential for increasing global participation for both prevention and removal efforts. From an educational standpoint, fisheries and the public should be made more aware of fisheries rules and regulations regarding gear use, gear limits, and proper onshore disposal, as well as implementing better mechanisms for tracking gear compliance.

Having this multipronged approach of prevention, removal, and education is vital to further our knowledge on ghost fishing, the factors that contribute to it, and what mechanisms (preventive, regulatory, educational, etc.) are best to reduce ghost fishing. Increased interaction between international organizations would further strengthen collaborative possibilities, promote more standardization of methods, and advance the sharing of ideas and programs that are found to be effective—all of which will ultimately help reduce the loss of marine life due to DFG and help sustain the world's fisheries for future generations.

Figure 5. A Hawaiian monk seal on large derelict net at Pearl and Hermes Atoll. (Photo Credit: NOAA) Permit no. PMNM-2013-001

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