2016 NOAA Marine Debris Program Report

Habitat

Marine Debris Impacts on Coastal and Benthic Habitats

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Marine debris produces a wide variety of environmental, economic, safety, health, and cultural impacts and is rapidly achieving recognition as a key anthropogenic threat to global oceanic ecosystems. A central theme of research on habitat degradation via marine debris is determining the impact of specific types of debris (abandoned or derelict fishing gear and plastics in particular) on sensitive habitats. In this paper, the impacts of marine debris are discussed as they affect coastal and ocean habitats, including sandy beaches, salt marshes, mangrove forests, coral reefs and hard bottom, seagrass, benthic sediments, and oyster reefs. Other important habitats—such as areas with kelp and macroalgae, rocky intertidal areas, and freshwater systems such as the Great Lakes region—are lacking research on the effects of marine debris and are in need of more attention regarding habitat impacts.

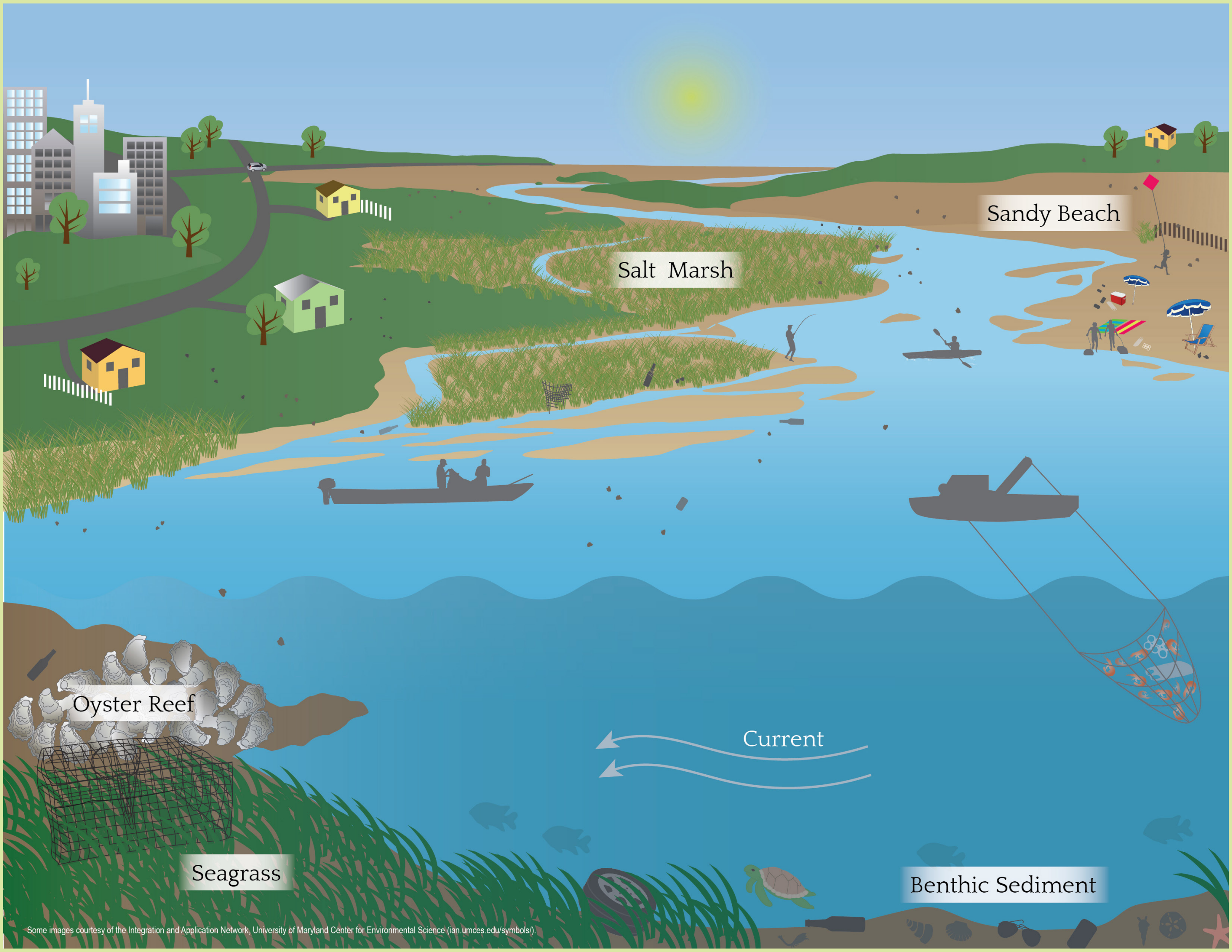
The accumulation of marine debris can alter and degrade marine habitats through physical damage caused by abrasion, shearing, or smothering, and can change the physical and chemical composition of sediments. Physical damage often impairs critical nurseries and refuges used by many different organisms that occupy these habitats and may reduce the quality of habitat for organisms whose daily activities (e.g., feeding, reproduction) require the use of specific environments. Degraded marine habitats reduce the resilience of marine life and their ability to survive in open waters and on the ocean floor. In addition, changes in marine habitats can alter complex marine ecosystems and ultimately affect yields of important commercial fisheries resources and reduce local biodiversity.

Although marine debris has been documented to cause physical damage to marine ecosystems, the damage to habitat-forming foundation species and other organisms utilizing marine habitats has not yet been fully characterized. Marine organisms and their habitats can become contaminated by potentially harmful chemical compounds leaching from debris items such as abandoned vessels or plastics. Additionally, the accumulation of microplastics in benthic and beach sediments may alter the quality of marine habitats for many animals by imposing uncertain physiological and toxicological risks on these inhabitants, ultimately including humans. The abundance of microplastics found in all marine habitats and their potential impacts to both the habitats and foundation species warrant continued investigation.

The accumulation and dispersal of marine debris can be caused by both natural disasters and anthropogenic sources. Storms, currents, and tides play a role in the movement of debris, which can lead to recurrent damage to marine species and habitats. Marine debris removal programs have been instrumental in reducing acute and historical accumulations and harmful impacts to sensitive marine habitats; however, removal work may also have unintended impacts on habitats, such as eliminating cover and creating open patches which may serve as substrate for colonizing organisms.

To date, very few large-scale studies have attempted to quantitatively and qualitatively assess the occurrence and magnitude of habitat impacts incurred by marine debris. Since marine habitats are exposed to multiple anthropogenic stressors, assessing the risks associated solely with the presence of marine debris presents considerable challenges. There is also a need for research evaluating the long-term impacts of marine debris on those organisms and communities living within, or associated with, these marine habitats. Overall, the consequences for ecosystem-wide impacts caused by marine debris, including the loss of ecosystem goods and services due to larger-scale effects of marine debris pollution, are multifaceted and remain to be fully understood.

INTRODUCTION



Some images courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

Figure 1. *This graphic depicts coastal habitats (salt marshes, seagrass beds, oyster reefs, sandy beaches, and benthic sediments) and many sources of how marine debris may be introduced into these habitats through human activities (urban areas, recreational and commercial fishers, recreational boaters, beachgoers, etc.). Graphic created by Catherine Polk (NOAA, National Ocean Service, National Centers for Coastal Ocean Science).*

Marine debris is rapidly achieving universal recognition as a key anthropogenic threat to global oceanic ecosystems and produces a wide variety of negative environmental, economic, safety, health, and cultural impacts (UNEP, 2009). Coastal and ocean habitats impacted by marine debris have been observed from the Earth's equator to the poles, and from shorelines, estuaries, and the sea surface to the ocean floor (Figure 1). The Marine Debris Act (33 U.S.C. 1951 et seq.) defines marine debris as any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment. This may include man-made products composed of materials such as plastic, glass, metals, or rubber, as well as derelict fishing gear and derelict vessels, and may range in size from micrometers (plastic pellets) to meters (shipwrecks) (UNEP, 2009; Lippiatt, Opfer, & Arthur, 2013; Bergmann, Gutow, & Klages, 2015).

Marine debris can enter rivers, streams, lakes, estuaries, and the ocean from land-based sources such as waste, run off, and sewage effluent. Debris also enters the marine environment through ocean-based sources, such as maritime and cruise industries, commercial fisheries, and recreational fishing and boating activities. Marine debris is transported throughout the world's ocean and water bodies, accumulating on beaches and within oceanic convergence zones and gyres. It can threaten marine and human life, transport chemical pollutants, interfere with navigation, and degrade habitats. The harmful effects of marine debris on wildlife are often evidenced by directly observing animals ingesting and becoming entangled in debris (Laist, 1987; Derraik, 2002; Katsanevakis, 2008; Gregory, 2009; Ryan, Moore, Van Franeker, & Moloney, 2009; Thompson, Moore, Vom Saal, & Swan, 2009; NOAA MDP, 2014a, b; Gall & Thompson, 2015).

Accurate estimates of how much marine debris is in the global ocean remain elusive, but the presence of debris is generally agreed to be ubiquitous (Ivar do Sul & Costa, 2007; Ribic, Sheavly, & Rugg, 2011; Woodall, Robinson, Rogers, Narayanaswamy, & Paterson, 2015). It has been estimated that 4.8 to 12.7 million metric tons of plastic waste entered the ocean in 2010 from 192 coastal countries (Jambeck *et al.*, 2015). This is expected to increase by an order of magnitude by 2025 if no improvements in waste management infrastructure occur (Jambeck *et al.*, 2015). The abundance and spatial distribution of marine debris is dependent on several factors, including the point of origin, ocean currents, wind patterns, and physiographic characteristics (Galgani *et al.*, 2000; Donohue, Boland, Sramek, & Antonelis, 2001). Pelagic marine debris can be found near the water's surface or suspended vertically in the upper water column, while benthic marine debris is found near or on the seabed. When marine debris accumulates in ocean basins, beaches, estuaries, and other submerged benthic habitats, it can cause reduced light levels in underlying waters, low oxygen levels, and other physical changes or degradation of these habitats (Goldberg, 1994; Uneputty & Evans, 1997). Although coastal habitats are closer to primary debris sources, open-ocean habitats found beyond the edge of the continental shelf are also impacted by marine debris, especially within surface convergence zones located north and south of the equator (Pichel *et al.*, 2007; Law *et al.*, 2010; Leichter, 2011; Cózar *et al.*, 2014).

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The localized accumulation of marine debris in a habitat can be influenced by wind, current, geography, and the proximity of human activity, such as urban areas and trade routes (Barnes, Galgani, Thompson, & Barlaz, 2009). Sub-Antarctic beaches have seen debris accumulation rates dependent on tides and onshore winds that can also remove debris or bury it and cause it to reappear later (Eriksson, Burton, Fitch, Schulz, & van den Hoff, 2013). Although the large scale Hawaiian commercial fishing industry uses longline fishing methods, there is a high presence of derelict trawl nets in Hawaiian coral reef habitats resulting from the seasonal oscillations of the convergence zone that allow trawl nets to be transported far from their point of entry, ending up in Hawaiian waters (Boland & Donohue, 2003).

Habitat degradation due to marine debris has far-reaching impacts on ocean biodiversity since many critical areas, such as coral reefs, mangroves, salt marshes, seagrass beds, and macroalgae serve as breeding grounds or nurseries for nearly all marine species. The movement of marine debris by tides, currents, and storms can result in recurrent damage to marine animals and habitats, either through repeated damage in situ or when transported any distance (Sheridan, Hill, Matthews, & Appledoorn, 2003; Lewis, Slade, Maxwell, & Matthews, 2009; Good, June, Etnier, & Broadhurst, 2010). In the wake of severe weather events, such as Hurricane Katrina in the Gulf of Mexico, immediate marine debris response efforts were directed toward field surveys, mapping hotspots of debris, and debris removal operations, all of which collected data that could later inform studies to directly assess associated habitat degradation (Munasinghe, 2007). Accelerated species extinctions and declines in global biodiversity are associated with habitat loss, thus making it critical to unravel the ecological consequences of marine debris (Myers *et al.*, 2013; Pimm *et al.*, 2014).

Larger-scale effects of marine debris pollution are multifaceted and remain to be fully understood, including cumulative impacts to ecosystem goods and services. The effects of marine debris on species at the population and community level are also largely unknown (Browne *et al.*, 2015). Fortunately, marine debris research and monitoring assessments are increasing in scope and complexity and garnering support as local, national, and international communities recognize the magnitude of global marine debris and its risk to critical and fragile aquatic habitats. Since many marine habitats experience multiple environmental and anthropogenic stressors, separating the risks associated with marine debris from those of other stressors is difficult (Derraik, 2002; Halpern *et al.*, 2009; Koelmans, Gouin, Thompson, Wallace, & Arthur, 2014). There is also the problem of assuming that all marine debris causes an impact on the organism or the habitat at all (Browne *et al.*, 2015).

This report synthesizes the state of science regarding marine debris impacts to coastal and marine habitats, highlights where knowledge is currently lacking, and recommends future research and assessment priorities.

Salt Marsh

Coastal salt marshes are considered a type of wetland that links land and saline water bodies (Adam, 1993). While a variety of grasses, herbs, and low shrubs can populate a salt marsh, in temperate zones, marsh grasses such as Spartina species can be the dominant plant. These areas are closely linked with the terrestrial environment; for instance, saltwater marshes can receive significant pulses of freshwater inflow (Barnette, 2001; Figure 1). Salt marshes differ from seagrass beds by being submerged only periodically and are not dominated by trees as mangrove habitats are (Adam, 1993). However, similar to seagrass beds and mangrove forests, salt marshes support extremely high primary and secondary productivity, with abundant and diverse fish and invertebrate species (Beck *et al.*, 2001). The importance of salt marshes was emphasized by Barbier . (2010), who stated that salt marshes “provide a high number of valuable benefits … including raw materials and food, coastal protection, erosion control, water purification, maintenance of fisheries, carbon sequestration, and tourism, recreation, education, and research.”

> **“When marine debris comes into contact with salt marshes, the marsh vegetation can entrap debris, keeping it within and sometimes deep into the marsh, especially after storms.”**

When marine debris comes into contact with salt marshes, the marsh vegetation can entrap debris, keeping it within and sometimes deep into the marsh, especially after storms (Viehman, Vander Pluym, & Schellinger, 2011). In Argentina, even crab burrows have been shown to work as passive traps for debris (Iribarne, Botto, Martinetto, & Gutierrez, 2000). One study observed that these burrows retained a significantly larger amount of plastic debris on the surface, and had larger amounts of buried debris in the sediment, than areas without crabs (Iribarne *et al*., 2000). Most debris in marshes, however, is concentrated in natural wrack lines (Viehman *et al*., 2011) and these accumulations don't just occur in locations close to populated areas. In Georgia, accumulation of debris in more remote marshes was attributed to strong currents and storms rather than direct littering from visitors accessing these sites (Lee & Sanders, 2015).

In a North Carolina marsh, Uhrin & Schellinger (2011) studied the damage to the dominant marsh vegetation, Spartina alterniflora, from marine debris. Wire crab pots and vehicle tires were secured in marsh plots for up to 13 weeks and then removed, after which the plots were monitored for recovery (Figure 2). Both the tires and crab pots caused broken or abraded grass stems, with the tires causing plant stems to be buried into the sediment leading to suffocation and complete plant loss. Derelict crab pots did not pose an immediate direct threat to marsh grass, as the grass recovered a few weeks after pot removal (Uhrin & Schellinger, 2011).

As with other habitats, debris in salt marshes damages the vegetation, which serves a crucial role for organisms that rely on marsh habitats. Heavy debris may even denude the marsh and pose entrapment hazards for fish, marine mammals, and birds, while small debris items can be ingested by birds, turtles, fish, and mussels (Viehman *et al*., 2011). Solid plastic debris, due to its smothering ability, may also alter such components of the marsh as primary productivity, invertebrate biomass, and nutrient exchange (Green, Boots, Blockley, Rocha, & Thompson, 2015). While removing such smothering debris as plastics, tires, and processed wood can help basic ecosystem functions, it is debatable if removing derelict crab traps that no longer pose an entrapment hazard to wildlife is in the best interest of the marsh, especially if the traps have been incorporated in the surrounding vegetation (Uhrin & Schellinger, 2011).

Sandy Beach

Sandy beaches, defined by sand, waves, and tides, provide habitat for a diversity of wildlife (Defeo *et al*., 2009). This fauna ranges from microorganisms that live between sand grains to birds and turtles using the beach for nesting (Defeo *et al*., 2009). Most of these species are not found in any other habitats, as they are uniquely adapted to the sandy beach environment (Defeo *et al*., 2009).

Marine debris accumulation associated with shorelines is well documented (Ribic, Johnson, & Cole, 1994; Silva-Iniguez & Fischer, 2003;

Figure 2. *A researcher monitors a vehicle tire and blue crab trap that were experimentally deployed on a fringing salt marsh as part of an impact study in Beaufort, North Carolina (left). The impact footprint of a vehicle tire in a fringing salt marsh in Beaufort, North Carolina (right). Photo Credit: NOAA.*

Figure 3. *Microplastic debris found on Midway Atoll in the Northwestern Hawaiian Islands (left; Photo Credit: NOAA). Plastic pellets, also called nurdles, used in the plastic manufacturing process (right; Photo Credit: Seba Sheavly, Sheavly Consultants, Inc.).*

Debrot, Meesters, Bron, & de León, 2013; Davis & Murphy, 2015; Lee & Sanders, 2015), since such areas are easy to access and littered beaches are not well tolerated due to aesthetic reasons. In Australia, the Tasmanian Parks and Wildlife Service found that fishing debris made up 20 percent of the total debris and 40 percent of the plastic debris found on its beaches (Jones, 1995). They concluded that marine debris on a beach can reduce the recreational and aesthetic value of the beach and can be hazardous to beachgoers and coastal wildlife (Jones, 1995; Leggett, Scherer, Curry, Bailey, & Haab, 2014). Economic consequences of beach litter have been recognized in many regions, including Great Britain (Newman, Watkins, Farmer, Brink, & Schweitzer, 2015), South Africa (Ballance, Ryan, & Turpie, 2000), Chile and Peru (Thiel, Hinojosa, Joschko, & Gutow, 2011), to reference a few. In a study in Southern California funded by the NOAA Marine Debris Program (Leggett *et al.*, 2014), Orange County residents were found to lose millions of dollars each year from beachgoers avoiding littered, local beaches in favor of choosing cleaner beaches that were farther away and that may cost more to reach. Not only are there lost revenue from decreased tourism and direct costs for beach-cleaning activities, but beach litter can also cause landscape deterioration and contamination of inland and coastal waters (Newman *et al.*, 2015).

The debris found on beaches can be washed up from the sea or be of terrestrial origin. The amount of litter that strands on beaches varies widely due to topography and prevailing winds, with the most litter on individual beaches found at the high-tide (or storm-level) line (Galgani, Hanke, & Maes, 2015). Eriksson *et al.* (2013) summarized several studies that showed how debris can wash up on beaches from the sea. These included wind factors interacting with the orientation of the beach, the proximity of tidal currents to fishing grounds, and even high wave energies that expose previously buried debris on the shore (Eriksson *et al.*, 2013). Other researchers add causes such as climate, the proximity to urban, industrial, and recreational areas, and shipping lanes to the list of covariates that influence debris accumulation (Galgani *et al.*, 2015). This creates a problem in which beach litter is not just confined to highly populated areas. Ribic, Sheavly, & Klavitter (2012) documented the findings from 23 surveys of marine debris found on Midway Atoll in the Pacific Ocean, far from high population densities. Beaches oriented toward the North Pacific Gyre and the Subtropical Convergence Zone contained the highest amount of debris (Ribic *et al.*, 2012).

An abundance of published literature exists on the amounts of litter found on sandy beaches and along shorelines as referenced above. However, much less is known about its impact on the habitat. Changes in sandy sediments in the intertidal zone due to the impacts of microplastics and plastic fragments have been reported (Carson, Colbert, Kaylor, & McDermid, 2011; Figure 3). The examination of sediment cores from Hawaiian beaches revealed that the presence of plastic pellets and fragments changed the physical properties of beaches, which showed increased permeability and lowered subsurface temperatures and were hypothesized to have potentially adverse effects on a variety of beach organisms (Carson *et al*., 2011). Even relatively modest decreases in subsurface temperatures could impact beach organisms, including those with temperature-dependent sex-determination such as sea turtles (Yntema & Mrosovsky 1982; Carson *et al*., 2011).

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Plastic pellets, used in industry, have been found on beaches in 17 countries (Stevenson, 2011). These pellets can adsorb contaminants, such as PCBs, PAHs, and organochlorine pesticides, when in high concentrations (Stevenson, 2011; Antunes, Frias, Micaelo, & Sobral, 2013). When the pellets degrade, these contaminants can then be released back into the sediment (Nakashima, Isobe, Kako, Itai, & Takahashi, 2012). In Japan, toxic metals leaching from plastic beach litter were found to potentially lead to accumulations in beach sediments over time (Nakashima *et al*., 2012). This was illustrated by the high amount of lead found in polyvinyl chloride fishing floats that washed ashore in Japan; it was estimated that up to 0.6 grams of lead a year could be leached onto one particular beach from these floats (Nakashima *et al*., 2012).

Sandy beaches are popular tourist and recreational destinations, resulting in much attention given to the presence of marine debris, especially when such debris causes economic impacts (Newman *et al*., 2015). Marine debris removal programs have been instrumental in reducing historical accumulations and harmful impacts to habitats such as sandy beaches, but removal can have consequences for those organisms that live there (Defeo *et al*., 2009). Wrack removal can disturb community structures, and sand grooming can remove plants and other organisms, leaving such areas open to wind erosion (Defeo *et al*., 2009). Through the years, plastic litter has become ubiquitous, even in remote island locations, posing risks from leaching toxic chemicals into the surrounding sand and sediment (Nakashima *et al*., 2012), and causing changes in substrate composition and parameters such as temperature (Carson *et al*., 2011). How this is affecting the long-term survival of native organisms is unknown. Ultimately, as discussed, marine debris may end up on beaches due to a number of factors and sources, but debris will continue to wash ashore unless it is prevented from entering the watershed in the first place.

Mangroves

Inhabiting the shores of protected coastal lagoons and estuaries in tropical and subtropical latitudes are several species of mangrove trees. Mangroves are important ecologically since they protect and stabilize coastlines in addition to enriching coastal waters (Kathiresan & Bingham, 2001). This habitat is structurally complex and diverse with terrestrial animals occupying the upper leafy canopy and a variety of aquatic animals living on or around the distinctive prop roots, making mangroves among the world's most productive ecosystems (Kathiresan & Bingham, 2001; Cordeiro & Costa, 2010). Mangrove forests are also popular for human activity as a source of food (hunting, fishing, and harvesting mollusks) and wood (Cordeiro & Costa, 2010). Because of their proximity to urban areas and the rapid advance of urbanization toward the coast in tropical regions, mangroves encounter a range of environmental stresses among which is marine debris (Kathiresan & Bingham, 2001; Cordeiro & Costa, 2010).

Whether directly littered in mangrove habitats or transported by wind and water, marine debris becomes trapped among mangrove trees and their aerial roots, which may block mangrove tidal channels and prove detrimental to nearshore habitats and their associated species (UNEP, 2009; Figure 4). In Brazil, Cordeiro & Costa (2010) surveyed mangrove stands and found the predominant litter type in terms of density was plastic (62.81 percent) and, by weight, wood (55.53 percent). The problems associated with debris accumulation like this include costs to the ecosystem by direct mortality of animal species and habitat suppression, as well as direct costs to the local economy by tourist avoidance (Cordeiro & Costa, 2010).

An island off the coast of Papua New Guinea showed unusually high loads of litter in its mangrove forests, with one 50 m section containing a combined weight of 889 kg of marine debris (90 percent plastic)(Smith, 2012). Though sparsely populated, the island was in close proximity to highly-populated regions and within prevailing currents, illustrating the problem of wind and wave transport (Smith, 2012). This high debris load was seen as a setback in rehabilitating depleted mangrove forests, as it smothered seedlings and created water quality issues in the surrounding bay (Smith, 2012). Mangrove forests act as both a trap and filter for debris, with larger debris like plastic bags, rope, and wooden flotsam trapped up front, and smaller debris penetrating deeper into the forest (Debrot *et al.*, 2013). Abandoned and derelict boats are another source of injury to mangrove habitats, causing damage to trees and prop roots, especially when remobilized during storms (Lord-Boring, Zelo, & Nixon, 2004).

Plastic debris can interfere directly with the ecological role of mangrove forests in the estuarine ecosystem, particularly since it can be retained for months, resisting extreme tidal events and seasonal riverine flushes. This was realized in a controlled study with tagged plastic debris in a Brazilian mangrove forest (Ivar do Sul, Costa, Silva-Cavalcanti, & Araújo, 2014). The investigators concluded that mangrove conservation is dependent on solving the plastic pollution issue, with source control a priority target (Ivar do Sul *et al.*, 2014). However, large plastic debris is not the only issue, as microplastics have recently been identified in the sediment of seven intertidal mangrove habitats studied in Singapore. Their effects on this habitat are still largely speculative, so further studies are planned to measure the presence of microplastics in mangrove biota and assess any toxicological impacts (Mohamed Nor & Obbard, 2014).

As with many of the other habitats discussed in this paper, there is research on the presence of marine debris in mangroves, but little research on actual impacts to the trees and their habitat. While abandoned boats can cause obvious physical damage, other marine debris effects are less

Figure 4. *Mangrove trees with debris caught in the prop roots in Florida (left; Photo Credit: NOAA) and large debris in a mangrove forest in Puerto Rico (right; Photo Credit: NOAA).*

BENTHIC HABITATS

Figure 5. *A derelict spiny lobster trap on seagrass (manatee grass, Syringodium filiforme) in the Florida Keys (left). A trap impact footprint after six months of experimental deployment on seagrass (manatee grass, Syringodium filiforme,) (right). Photo Credit: NOAA.*

apparent. Removal of debris items from mangrove habitats is seen as a solution for recovery from impacts caused by the debris (Lord-Boring *et al*., 2004; Ivar do Sul *et al*., 2014).

Seagrass

Seagrass ecosystems exist worldwide and are one of the most productive and economically important habitats in the coastal ocean. Seagrasses can be sensitive indicators of environmental quality in terms of water clarity and nutrient levels (Dennison *et al*., 1993), can provide valuable ecosystem services (Orth *et al*., 2006), and can support a diverse assemblage of fauna, many with important commercial value (Beck *et al*., 2001). Seagrass beds may also be located near other coastal habitats, such as salt marshes (in temperate regions) (Figure 1) or mangroves and coral reefs (in tropical regions), which encourages cross-habitat use by fishes and invertebrates (Beck *et al*., 2001). Seagrasses are vulnerable to debris found in runoff from land or generated from coastal activities (i.e., boating, beach use) due to their location along coastlines and nearshore environments (Orth *et al*., 2006).

Because seagrasses support a number of recreational and commercial fishery species, they are susceptible to impacts not only from the active use of fishing gear but from derelict gear as well. Fishing gear has the ability to resuspend sediment, disturb the rhizome, and impact the root structure of seagrasses (Barnette, 2001). Disturbance to seagrass habitats from derelict spiny lobster traps was well-documented by Sheridan *et al.* (2003) in the Florida Keys, Puerto Rico, and the Virgin Islands, where commercial trap fisheries exist. Not only were these traps found to flatten the plants, but the trap lines could also shear and abrade them (Sheridan *et al*., 2003). In the Florida Keys National Marine Sanctuary, it was recently estimated that over 85,000 derelict traps like these were present on the seafloor, along with over 1,000,000 remnants of traps (Uhrin, Matthews, & Lewis, 2014), all with the potential to damage sensitive seagrasses.

Lost traps also cause continuous damage when moved by storms and wave action. In Biscayne Bay, Florida, traps caused a seven percent loss of turtlegrass (*Thalassia testudinum*) after one week and a 26 percent loss of turtlegrass after one month (Sheridan *et al*., 2003). In the U.S. Virgin Islands, the placement of lobster traps on seagrass caused matted or discolored patches (Sheridan *et al*., 2005). The severity of damage to seagrass from abandoned lobster traps is also dependent upon the grass species and the length of time the trap is in contact with the grass. After six weeks of trap contact time, *T. testudinum* was able to recover within four months, while *Syringodium filiforme* densities remained depressed six months after injury (Uhrin, Fonseca, & DiDomenico, 2005)(Figure 5). There has also been documented evidence of damage to seagrass beds due to abandoned or derelict fishing vessels. A study of U.S. territories in the Caribbean and the Pacific Ocean saw active erosion to seagrass beds caused by abandoned vessels (Lord-Boring *et al*., 2004). Damage to seagrass habitats varied widely, but the most damage to seagrass occurred from vessels moved during storms (Lord-Boring *et al*., 2004).

The most obvious effect of marine debris on seagrass habitats is the damage to vegetation by breaking and abrading stems and even denuding whole sections of seagrass beds (Sheridan *et al*., 2003; Uhrin *et al*., 2014). Other researchers have found that habitat damage from derelict traps is often assumed, but that it greatly depends on trap placement and the strength of wave action (Clark, Pittman, Battista, & Caldow, 2012). Removing the debris from impacted areas does allow for the vegetation to return, but the time to recolonize depends on the species of grass affected (Uhrin *et al*., 2005). As in salt marshes, debris such as derelict traps may become part of the surrounding habitat and recruit fish and other organisms. Removal of debris in these instances should be carefully assessed (Battista, Clark, & Murphy, 2012).

Oyster Reefs

Oyster (Family: Ostreidae) reef habitats are located in the benthic zone of estuarine areas where hard bottoms exist with sufficient currents (Barnette, 2001). The reefs can be variable, ranging from small scattered clumps of oysters to massive mounds of living oysters and dead shells (Bahr & Lanier, 1981). Oyster reefs can be subtidal or intertidal along marsh peripheries or in open bays (Bahr & Lanier, 1981; Figure 1). Research has shown that human activity has made oyster reefs one of the most impacted of marine habitats (Halpern *et al*., 2009). Impacts from marine debris, one of the top human threats to marine ecosystems, can affect more than just the oysters, as over 300 species of macrofauna have been found associated with oyster reef habitat (Bahr & Lanier, 1981).

As in other marine habitats, plastic litter can negatively affect oyster reefs. When plastics rest on the seafloor in these habitats, smothering, ingestion, and exposure to toxicants can occur. Plastic litter may also inhibit gas exchange between the sediment and water rendering areas devoid of oxygen (Wurpel, Van den Akker, Pors, & Ten Wolde, 2011). Microplastic debris is also a concern with oysters. Particles may be ingested and accumulated by oysters, leading to physical effects (Davidson 2012). Ward & Kach (2009) conducted laboratory tests with oysters and mussels (*Mytilus edulis*) on their ability to uptake polystyrene beads. The beads were ingested when incorporated into aggregates composed of their normal food sources. After ingestion, the beads were transported to their digestive glands, creating possibilities for toxicological effects and the potential to transfer microparticles to higher trophic levels (Ward & Kach, 2009). This potential for transference was seen by Van

Figure 6. *A Virginia commercial waterman retrieving derelict blue crab pots with extensive biofouling, including oysters. Photo Credit: CCRM/VIMS.*

"Impacts from marine debris, one of the top human threats to marine ecosystems, can affect more than just the oysters, as over 300 species of macrofauna have been found associated with oyster reef habitat."

Cauwenberghe & Janssen (2014) after purchasing farm-raised mussels and oysters in Germany and France. Both bivalve species contained microplastics, subjecting shellfish consumers to an annual dietary exposure of approximately 11,000 microplastics per year (Van Cauwenberghe & Janssen, 2014).

Apart from these damaging impacts, marine debris has also been shown to provide substrate for larval settlement in areas where hard structure is lacking. Derelict crab pots and fishing traps have been revealed to provide oyster habitat in several areas of the U.S. East Coast (Havens, Bilkovic, Stanhope, & Angstadt, 2011), with high numbers of live oysters found on derelict pots in the Chesapeake Bay (Havens *et al.*, 2011; Figure 6). Of fishing traps retrieved from North Carolina marshes, 17 percent had recruited oysters, and a number of traps collected in Virginia contained over 100 attached oysters (Voss, Wood, Browder, & Michaelis, 2012; Bilkovic, Havens, Stanhope, & Angstadt, 2014).

While in some situations the presence of marine debris has been observed to provide new habitat for oysters (Havens *et al.*, 2011), marine debris has also caused harmful smothering, entanglement, changes in substrate, and anoxic conditions (Wurpel *et al.*, 2011). Ingestion of microplastics by bivalves has led to concerns about the potential of transference to human consumers (Van Cauwenberghe & Janssen, 2014). Further investigation of the long-term effects of microplastics on oyster habitats would be a next logical step.

Coral-Dominated Habitats

Coral reefs, geologic formations that provide coastal protection from the ocean's destructive forces, have the highest biological diversity in the marine environment (Yap, 2012). They provide habitat to one-third of all marine fish species and tens of thousands of other organisms, yet only cover 0.2% of the ocean's area (Barnette, 2001). They have also served as a basis of human sustenance in many coastal areas in the tropics and subtropics (Yap, 2012). Living coral reef growth is dependent on environmental conditions such as wave energy, water quality, turbidity, salinity, tidal regime, and light (Pandolfi, 2011). As these encrusting and structure-forming species produce their complex and delicate skeletons, the fragile nature of these structures leads them to be vulnerable to fishery-related impacts (Barnette, 2001).

The high biological diversity of coral reefs also makes them popular commercial and recreational fishing grounds, which often results in the presence of derelict fishing gear (DFG) (Figure 7). DFG is known to cause significant and persistent threats to the coral reef ecosystems in many well-studied areas, such as the Northwestern Hawaiian Islands (NWHI), main Hawaiian Islands, Florida Keys National Marine Sanctuary, and Gray's Reef National Marine Sanctuary (Donohue *et al.*, 2001; Chiappone, White, Swanson, & Miller, 2002; Asoh, Yoshikawa, Kosaki, & Marschall, 2004; Chiappone, Dienes, Swanson, & Miller, 2005; Dameron, Parke, Albins, & Brainard, 2007; Morishige, Donohue, Flint, Swenson, & Woolaway, 2007; Bauer, Kendall, & Jeffrey, 2008; Lewis *et al.*, 2009; Cooper & Corcoran, 2010; Good *et al.*, 2010). Though much of the DFG found in these areas may be of local fisheries origin, floating DFG (such as fishing ropes, nets, and lines) may circulate in ocean gyres to convergence zones, causing impacts to habitats far from their point of origin (Kubota, 1994). For example, DFG originating around the Pacific Rim (Japan to Alaska to California) may become snagged on the coral reefs of the NWHI due to its bathymetry and geography (Kubota, 1994; Donohue, Brainard, Parke, & Foley, 2000; Donohue *et al.*, 2001). Reef geography can also influence the amount of DFG that can become snagged on the reef structure. For example, DFG may be forced over the outlying coral

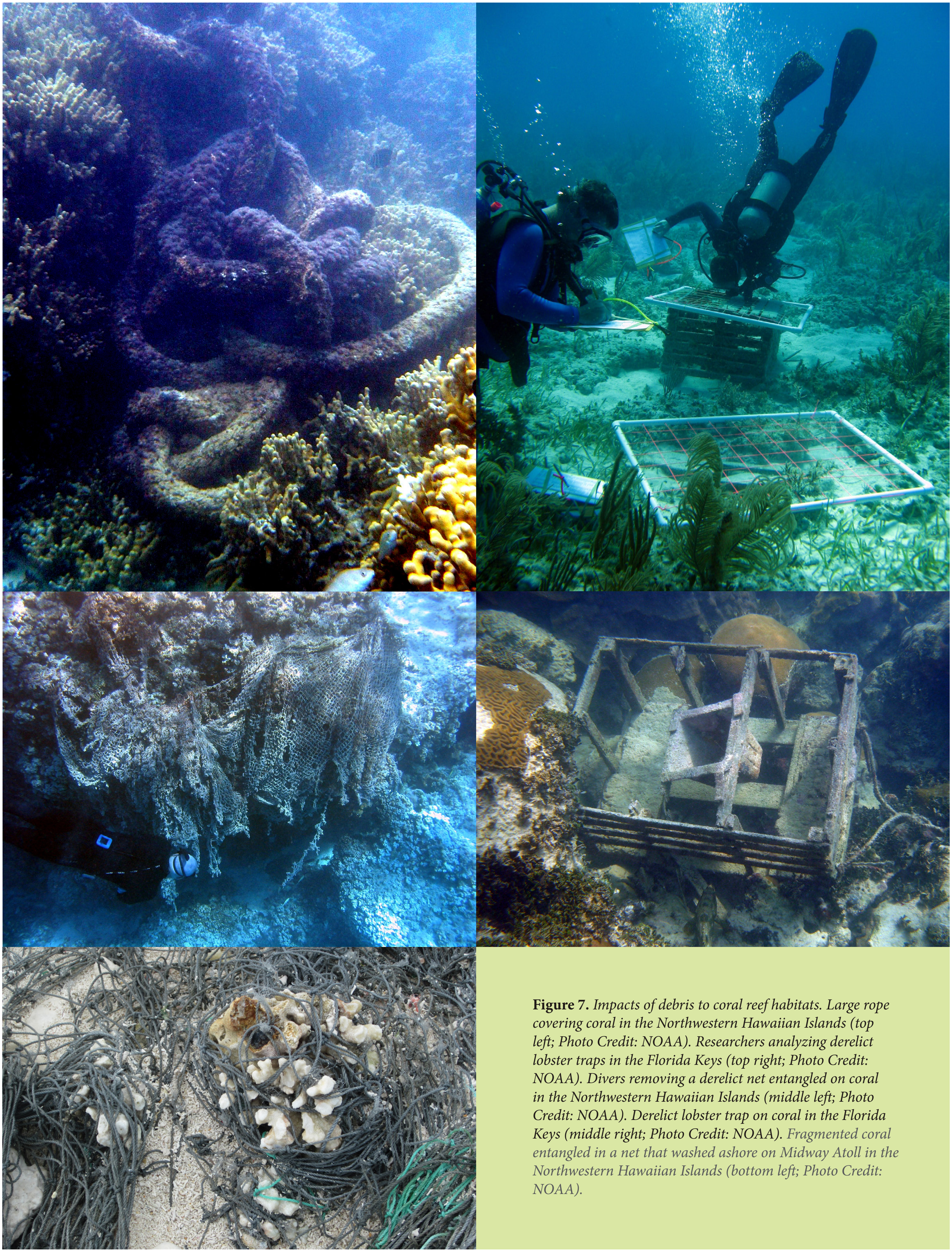

Figure 7. *Impacts of debris to coral reef habitats. Large rope covering coral in the Northwestern Hawaiian Islands (top left; Photo Credit: NOAA). Researchers analyzing derelict lobster traps in the Florida Keys (top right; Photo Credit: NOAA). Divers removing a derelict net entangled on coral in the Northwestern Hawaiian Islands (middle left; Photo Credit: NOAA). Derelict lobster trap on coral in the Florida Keys (middle right; Photo Credit: NOAA). Fragmented coral entangled in a net that washed ashore on Midway Atoll in the Northwestern Hawaiian Islands (bottom left; Photo Credit: NOAA).*

structure of some North Pacific Ocean barrier reefs to reside in the calmer interior waters of their lagoons (Donohue *et al.*, 2001). This DFG often remains in these shallow reefs due to the protected and low-energy conditions created by the barrier reefs (Dameron *et al.*, 2007).

Damage to reef-forming or hard corals (i.e., scleractinian corals) can reduce the integrity of coral reef ecosystems, since hard corals provide the substrate from which the reef structure is formed. As debris accumulates, it can entangle branching species of hard corals, resulting in fragmentation and abrasion (Figure 7) and potentially reducing habitat heterogeneity and providing open substrate for macroalgal colonization (UNEP, 2009). Live coral polyps can be abraded and scoured by DFG, which can potentially lead to major alterations in reef structure and destruction of the reef's skeleton (Pichel, 2003; Heifetz, Stone, & Shotwell, 2009). In the NWHI, for example, lost trawl gear damaged or destroyed fragile coral reef systems (Donohue *et al.*, 2001) with an estimated accumulation rate of 52 metric tons per year (Dameron *et al.*, 2007). Below are some examples of damage caused by marine debris in three types of reef habitats (Figure 7).

SHALLOW CORAL REEFS

Abandoned or derelict traps and pots pose multiple threats to coral reef habitats. Derelict lobster traps in the coral reefs of Puerto Rico, the U.S. Virgin Islands, and the Florida Keys damage hard and soft corals by abrading, shearing, and flattening organisms (Figure 7)(Sheridan *et al.*, 2003; Marshak, Hill, Sheridan, Sharer, & Appeldoorn, 2008). While direct damage or destruction of hard coral and other sensitive habitats is caused by DFG such as nets, traps, anchors, or boat strikes, further damage may be inflicted when the debris is moved around by tides, currents, and storms.

Although destructive fishing practices and DFG such as gill nets, traps, and anchors have been implicated in the decline of hard coral reef ecosystems, the adverse impacts of hook and line fishing have also been recognized (Asoh *et al.*, 2004). Hook and line gear (e.g., monofilament line) is used by both commercial and recreational fishermen and contributes significantly to marine debris, especially in shallow waters. Intensive fishing can be a major cause of death for corals due to the abrasion or destruction of fragile coral polyps from fishing line, hooks, and weights (Yoshikawa & Asoh, 2004). Derelict hook and line gear can also entangle corals, causing significant damage or death (Asoh *et al.*, 2004; Yoshikawa & Asoh, 2004).

Abandoned and derelict vessels are another means of degrading coral reef habitats, via physical contact during initial impact and from subsequent movement by storms, currents, and tides. The release of fuel, anti-fouling paints, and other chemicals from these vessels can also occur. The potential for the continual slow-release of biocides aimed to inhibit settlement of marine organisms, and the transport of such contaminated particles around reef systems, constitutes a significant ecological risk (Jones, 2007). Further, iron or other metal components in a fishing vessel shipwrecked on an isolated atoll in the central Pacific Ocean were hypothesized to play a role in the shift from hard coral to macroalgal species at the impact site, which led to a severe loss of coral reef habitat (Work, Aeby, & Maragos, 2008). A ship grounding on a coral reef at Rose Atoll in American Samoa changed the habitat there, leading to rapid overgrowth of cyanobacteria and an abundance of herbivorous fishes near the impact site (Schroeder, Green, DeMartini, & Kenyon, 2008). For this study, the investigators hypothesized that corroding metal debris from the shipwreck stimulated and maintained blooms of opportunistic algae species and associated herbivorous fishes for at least 13 years after the initial impact (Schroeder *et al.*, 2008). Similar shifts from coral habitat to algal-dominated communities have been reported in other coral reefs where ship groundings or anchor damage occurred (Rogers & Garrison, 2001; Work *et al.*, 2008). Such long-term changes result from the impacts on the reef-building community and influence reef function and structure (Schroeder *et al.*, 2008).

The direct threats from fishing debris and their by-products are not the only marine debris issues concerning coral reef habitats. Diverse debris items such as building materials, plastics, aluminum cans, tires, and even disposable diapers were documented by Richards & Beger (2011) in the coral habitat of Majuro Atoll in the Marshall Islands. A significant relationship between coral cover and debris was found, with coral cover decreasing as macro-debris cover increased.

This high density of macro-debris also impacted the coral habitat by reducing the diversity of the coral community (Richards & Beger, 2011). More recently, Hall, Berry, Rintoul, and Hoogenboom (2015) discovered the ability of scleractinian corals off the coast of Australia to ingest microplastics. High concentrations of microplastic debris could thus potentially impair the health of corals. It was found that corals may mistake microplastics for prey and can consume up to 50 μg of plastic at a rate similar to their consumption of plankton. It is uncertain how this ingestion affects coral energetics and growth, or if reef growth in general is threatened (Hall *et al*., 2015).

DEEP SEA CORAL REEFS

Research on the effects of marine debris on deep sea coral reefs is important, as this habitat also comes into contact with debris in a variety of ways. For instance, plastic litter can sink to the seafloor and become concentrated (Engler, 2012). As with shallow coral reefs, deep sea corals also encounter microplastics. Deep sea corals from the Indian Ocean were sampled from several sites, with all samples containing plastic microfibers (Woodall *et al*., 2014). A wide variety of polymer types were detected, showing complex accumulation and deposition of microfibers in the deep sea arising from a variety of domestic and industrial sources. The actual physical effects of the microplastics are unknown, but substantial quantities were also found in the surrounding deep-sea sediments (Woodall *et al*., 2014). Plastic debris, including monofilament fishing line, was observed off the California coast in deep benthic habitats populated with gorgonian corals, but disturbance was low and some debris was even used for shelter by fish and invertebrates (Watters, Yoklavich, Love, & Schroeder, 2010). In cold water corals on the seafloor of the Aleutian Islands, disturbances from bottom fishing gear were observed in each of twenty-five transects, with derelict longline gear found in five of the transects (Stone, 2006). In the Tyrrhenian Sea, fishing gear debris was observed covering, abrading, and hanging from deep rocky habitats, with over half of the recorded debris directly impacting benthic organisms such as gorgonians, black coral, and sponges (Angiolillo *et al*., 2015). Anthropogenic debris in the deep sea is much less widely investigated than more shallow areas due to sampling difficulties, inaccessibility, and high costs, even though this area accounts for almost half of the planet's surface (Lippiatt *et al*., 2013; Galgani *et al*., 2015).

HARD BOTTOM CORAL

Hard bottoms are submerged rock formations often colonized by reef species (SAFMC, n.d.). As with shallow and deep sea reef habitats, species important to commercial and recreational fisheries reside in these areas along with sessile invertebrates (Wahl, 2009). In the Florida Keys, annual trap losses reported by fishers were typically 10 to 20 percent of their total traps fished—about 50,000 to 100,000 traps—and this many abandoned and derelict traps can have a significant effect on the reef environment over an extended period of time (Lewis *et al*., 2009). In the study by Lewis *et al*. (2009), lobster traps were placed on hard bottom and reef sites off the coast of Florida to determine the extent of damage to the habitats from trap movement. Trap movement due to sustained winds caused sessile fauna to be scraped, fragmented, and dislodged. It was thus hypothesized "that trap fishing is a significant anthropogenic factor shaping the structure of coral reefs and hard bottom communities in the Florida Keys" due to the large number of traps deployed and lost each season (Lewis *et al*., 2009).

Gray's Reef National Marine Sanctuary (GRNMS) in the South Atlantic Bight has a well-known hard bottom habitat; Bauer *et al*. (2008) observed an abundance of fishing debris in this area, with most debris occurring in regions of high boat density. Derelict fishing gear, especially hook and line, was observed more often in the crevices, changes in elevation, and overhangs of ledges targeted by fishermen than in sand and sparse live bottom sites. Despite their limited area, the ledges were considered highly vulnerable to debris accumulation, which was important since they support diverse benthic communities (Bauer *et al*., 2008). These ledges boast complex communities of large sponges, gorgonians, and branching hard corals that can snag, trap, and entangle debris (Bauer, Kendall, & McFall, 2010). An earlier study at GRNMS (Kendall, Bauer, & Jeffrey, 2007) discovered that the majority of debris was on these densely colonized ledge habitats and urged that ledges be given priority for debris mitigation and removal. Another study of a hard bottom area found an intermodal shipping container had fallen into the deep sea area of Monterey Bay National Marine Sanctuary (Taylor *et al.*, 2014). The container was dominated by megafauna markedly dissimilar from the surrounding natural hard substrata. It was hypothesized that the faunal assemblage on the container was still at an early successional stage or that those species present represented ones tolerant of the container's potentially toxic surface paint (Taylor *et al.*, 2014).

A wide variety of debris, including derelict fishing gear, abandoned vessels, plastics, and lobster traps, have caused coral reef habitats to suffer from abrasion, fragmentation, and alteration of their structure; entanglement of the coral organisms and other organisms that inhabit the reefs; smothering; and the ingestion of microplastics and chemical contaminants. Viehman, Thur, & Piniak (2009), in summarizing several research studies, stated that recovery of damaged coral reef habitats, such as that from abandoned vessels, can take years. This recovery may then be only temporary or the damaged reef may convert permanently to another habitat type (i.e., hard bottom, macroalgae, sand) rather than to the pre-injury coral reef habitat (Viehman *et al.*, 2009). The capacity of coral reefs to absorb injury and retain the same basic identity may be reduced, however, by human actions such as overfishing and coastal eutrophication (Folke *et al.*, 2004). Thus the resilience of coral reef and hard bottom habitats to marine debris disturbances may not be apparent for years to come (Viehman *et al.*, 2009). The damage to these habitats may also jeopardize future tourism and can hurt fisheries development, leading to revenue losses (UNEP, 2009).

Benthic Sediment

Benthic sediment can be comprised of a wide variety of coarse sands, shell hash, fine silts, and muds (Barnette, 2001). This habitat can support a relatively sedentary macrofaunal community, among other organisms, that can have an important role in cycling nutrients between the sediments and the water column (Dauer, 1993). While some researchers suggest that sand and mud bottom habitats may be less affected by marine debris than more sensitive bottom habitats, such as seagrass or coral (Barnette, 2001), impacts from this debris can affect the complexity of benthic sediments available for a diverse set of animal, plant, and algal communities (Gilardi *et al.*, 2010).

As with the other habitats discussed in this paper, abandoned and derelict fishing nets can impact benthic environments by smothering, abrading, and changing the sea bottom structure (Gilardi *et al.*, 2010). Derelict nets can modify the sea floor by scouring the seabed and trapping fine sediment, which can suffocate plants and animals (Gilardi *et al.*, 2010). Visual documentation of nets observed in the Puget Sound and the Northwest Straits suggests that scouring and sedimentation under derelict nets is greater than in areas devoid of debris (Good *et al.*, 2010). The presence of these nets can lead to suffocation and elimination of sessile fauna and can also prevent fish and invertebrates from accessing their habitat (Good *et al.*, 2010).

Plastic debris, including monofilament fishing line, was observed in one long-term study off the California coast in deep benthic habitats, but disturbance was low and some debris was even used for shelter by fish and invertebrates. The highest debris densities occurred close to ports and increased significantly over the 15 years of the study (Watters *et al.*, 2010). In a controlled study in the Aegean Sea, plastic bottles and glass jars were placed on soft bottom habitats for a year. The debris provided refuge and reproduction sites for many mobile species, but the change from soft bottom to hard bottom displaced indigenous fauna due to predation or competition from invading species (Katsanevakis, Verriopoulos, Nicolaidou, & Thessalou-Legaki, 2007). In another controlled study with both conventional and biodegradable plastic bags, marine assemblages were rapidly altered after nine weeks of the bags making contact with the sediment. Plastic bags on the sediment caused anoxic conditions, reduced primary productivity and organic matter, and lowered infaunal invertebrate abundance (Green *et al.*, 2015). A review by Moore (2008) stated that the accumulation of plastics on benthic sediments can inhibit gas exchange between overlying waters

CONCLUSION

and sediment pore waters while smothering benthic inhabitants.

The discovery of microplastics in benthic habitats is added concern for the consequences of marine debris, as they can be ingested by filter-feeding invertebrates, potentially producing deleterious effects to the organisms as well as their predators (Browne, Dissanayake, Galloway, Lowe, & Thompson, 2008; von Moos, Burkhardt-Holm, & Köhler, 2012; Fisner, Taniguchi, Moreira, Bícego, & Turra, 2013). Currently, there is no direct evidence of population-level effects from microplastics, but the impact on benthic habitats could be significant given that microplastics also have the ability to adsorb contaminants (Thompson *et al.*, 2004; Teuten, Rowland, Galloway, & Thompson, 2007; Arthur, Baker, & Bamford, 2009; Ryan *et al.*, 2009; Law *et al.*, 2010; Ivar do Sul & Costa, 2014).The few studies on the effects of marine debris on benthic sediment habitats point to similarities with impacts discussed within the other habitat sections. The rising importance of microplastic research will shed further light on any benthic sediment effects.

State of the Science

The degradation of aquatic habitats due to marine debris poses potentially serious threats to the health of ocean and coastal ecosystems and living marine resources. Habitat degradation due to marine debris has far-reaching impacts on biodiversity since many critical areas, such as coral reefs, mangroves, marshes, and seagrass, serve as breeding grounds or nurseries for nearly all marine species. Marine debris not only damages habitats directly via physical and chemical impacts, but it can also lead to reduced recruitment and reproduction for certain species, which may indirectly alter or degrade critical nurseries and other fragile ecosystems (Laist, 1987; Derraik, 2002; Katsanevakis, 2008; Gregory, 2009; Ryan *et al.*, 2009; Thompson *et al.*, 2009; NOAA MDP, 2014a, b; Gall & Thompson, 2015). Accelerated species extinctions and declines in global biodiversity are associated with habitat loss, thus making it critical to unravel the ecological consequences associated with marine debris (Myers *et al.*, 2013; Pimm *et al.*, 2014; Browne *et al.*, 2015).

The impacts of debris on marine habitats vary in scope depending on the type, quantity, and location of the debris, as well as the vulnerability of the habitat. Although direct physical damage to marine habitats such as coral reefs, benthic zones, sandy beaches, and mangroves has been discussed, all habitats in this paper are in need of additional research. For instance, while damage to shallow marine habitats has been documented, the extent and range of habitat impacts still remain to be fully characterized and measured. Monitoring and assessment studies are needed that examine multiple habitats simultaneously (e.g., coral reefs and mangroves) and focus on the abundance, source, distribution, and composition of marine debris in sensitive or critical habitats. Marine debris can also alter habitat below the ocean's surface on the deep sea bed. However, due to the technical challenges and prohibitive costs of conducting research in the deep sea, little is known about the abundance, extent, and types of marine debris present and the impacts on this vast habitat (Schlining *et al.*, 2013). In the open ocean, debris concentrations, especially plastics, have been reported in all major subtropical oceanic gyres (Cózar *et al.*, 2014). Animals are more likely to encounter debris in convergence zones within the gyres, but comprehensive impact assessments of marine debris on these vital and productive floating habitats are lacking (Cózar *et al.*, 2014).

Other coastal and ocean habitats are also lacking basic information on the effects of marine debris, and so were not described in detail in this report. This includes floating macroalgae (i.e., *Sargassum*) and rocky intertidal zones. The abundance of native and invasive organisms associated with floating marine debris and macroalgae has been detailed (Carpenter & Smith, 1972; Lewis, Riddle, & Smith, 2005; Wei, Rowe, Nunnally, & Wicksten, 2012; Kiessling, Gutow, & Thiel, 2015), but the actual effect of marine debris on this habitat has not. Likewise, marine debris effects on rocky intertidal habitats have been little-studied, perhaps due to the difficulty of accessing this habitat. These areas have the disadvantage of easily accumulating and trapping debris due to the very nature of their structure (Moore, Gregorio, Carreon, Weisberg, & Leecaster, 2001; Eriksson & Burton, 2003; Thiel *et al*., 2013), highlighting the importance of further research in this area.

The Great Lakes are another area that lacks comprehensive research on the effects of marine debris on habitats. The Great Lakes constitute the largest freshwater ecosystem in the world, but they have suffered years of degradation from toxic contamination, destruction of coastal wetlands, nonpoint source pollution, and invasive species (NOAA, 2016). Currently, most research on Great Lakes debris is about enumerating plastic debris (Eriksen *et al*., 2013; Zbyszewski, Corcoran, & Hockin, 2014; Driedger, Dürr, Mitchell, & Van Cappellen, 2015) and not about the effects of marine debris on various Great Lakes habitats. Sources of plastic debris to the Great Lakes include microplastic beads from consumer products, pellets from the plastic manufacturing industry, and waste from beachgoers, shipping, and fishing activities (Driedger *et al*., 2015). How this plastic debris impacts Great Lakes habitats (marshes, benthic sediments, etc.) requires investigation.

The size of debris items in all habitats is also an issue. Large debris items are less mobile and have a greater potential to disturb marine habitats, but effects can be easier to assess (Lippiatt *et al*., 2013). Derelict fishing gear and other large, blanketing debris have been known to damage coral reefs by smothering, breaking apart, or abrading corals, modifying reef structure, injuring or killing associated plants and organisms, and impairing critical nurseries and refuges of many marine organisms (Donohue *et al*., 2001; Chiappone *et al*., 2002; Asoh *et al*., 2004; Chiappone *et al*., 2005; Dameron *et al*., 2007; Morishige *et al*., 2007; Bauer *et al*., 2008; Lewis *et al*., 2009; Cooper & Corcoran, 2010; Good *et al*., 2010). Conversely, some debris is actually seen as helpful or beneficial by providing extra habitat and cover for sessile and benthic organisms (Havens *et al*., 2011; Voss *et al*., 2012; Bilkovic *et al*., 2014); however, most debris, like derelict nets and plastics, can impact benthic environments by smothering, abrading, and changing the sea bottom structure (Wurpel *et al*., 2011; Green *et al*., 2015).

Smaller debris items, particularly microplastics, can be present in many habitats, such as benthic zones and coral reefs, but the challenge occurs in trying to determine their extent (Lippiatt *et al*., 2013). The abundance of microplastics in marine habitats suggests their impact could be significant. Microplastics often arrive in these locations when larger pieces of plastic debris degrade into smaller pieces by the actions of wind, waves, and sun, causing them to break into small (<5 mm) microplastic particles (Thompson *et al*., 2004; Arthur *et al*., 2009; Barnes *et al*., 2009; Law *et al*., 2010; Andrady, 2011). Much of the anthropogenic debris collected during surface water trawls consists of microplastics, which present new threats to the marine environment when ingested by marine organisms or when particles sink and become integrated into sediments (Thompson *et al*., 2004; Arthur *et al*., 2009; Barnes *et al*., 2009; Law *et al*., 2010; Thiel *et al*., 2013). Microplastics can thus directly impact marine habitats by altering the natural components of sediments and ultimately affecting local diversity and ecological processes (Wright, Thompson, & Galloway, 2013; Browne *et al*., 2015).

While many programs have removed vast amounts of marine debris from beaches, watersheds, and the marine environment (i.e., UNEP, 2009; Jung, Sung, Chun, & Keel, 2010; Van Cauwenberghe, Vanreusel, Mees, & Janssen, 2013), it is the lasting impacts on these habitats that are important. Marine debris removal programs, following best management practices, have reduced potential damage to marine species and habitats, engaged commercial fisherman and local communities in the removal process, and recycled or repurposed fishing gear and other debris (Guillory, Perry, & VanderKooy, 2001; Lippiatt *et al*., 2013; Arthur, Sutton-Grier, Murphy, & Bamford, 2014; Bilkovic *et al*., 2014). An evaluation of the habitat benefits due to debris removal will be important to secure support for future debris removal efforts.
It is crucial to develop accurate estimates of the impacts of marine

debris on habitats and community structure in order to identify and prioritize actions that governments, researchers, and other stakeholders can take to reduce those impacts.

As demonstrated in this discussion of marine debris on coastal and ocean habitats, much research is still needed. Recommendations for addressing key gaps in knowledge regarding marine debris impacts to the habitats discussed in this report and others yet to be studied include the following:

- complete targeted assessments in specific geographic locations and habitat types where data are minimal or lacking (i.e., Great Lakes, floating macroalgae);
- identify or create better tools for detecting and quantifying marine debris impacts in less accessible habitats (i.e., rocky intertidal zones, deep sea);
- assess shifts in the physical habitats, and in the organisms that live in those habitats, caused by the introduction of marine debris;
- incorporate monitoring of habitat recovery after any debris removal to estimate habitat recovery rates;
- determine estimates of residence times of marine debris and the length of time to see noticeable impacts; and
- conduct assessments of the population- and community-level effects of marine debris on foundation (habitat-forming) species.

Evaluating the cradle-to-grave (or cradle-to-cradle) process for plastics and other consumables could reduce our overall consumption of resources and the amount of material that enters habitats as marine debris (CA OPC, 2008; Ivar do Sul & Costa, 2014). To achieve this goal, it is imperative to educate local and global communities about marine debris prevention and to promote the development of universal management strategies to restore, protect, and conserve ocean health worldwide.

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