Marine Debris in the North Pacific

A Summary of Existing Information and Identification of Data Gaps

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BPA	bisphenol A
DDT	dichlorodiphenyltrichloroethane
ENSO	El Nino/Southern Oscillation
ESA	Endangered Species Act
IMDCC	Interagency Marine Debris Coordinating Committee
km	kilometer
m	meter
mm	millimeter
NMDMP	National Marine Debris Monitoring Program
NOAA	National Oceanic and Atmospheric Administration
NWHI-MNM	Northwestern Hawaiian Islands – Marine National Monument
POP	persistent organic pollutant
PCB	polychlorinated biphenyls
PAH	polycyclic aromatic hydrocarbons
SST	sea surface temperature
STCZ	Subtropical Convergence Zone
TZCF	Transition Zone Chlorophyll Front

1.0 INTRODUCTION

Marine debris can degrade ocean habitats, endanger marine and coastal wildlife, interfere with navigation, result in economic losses, and threaten human health and safety. Beginning in the 1970's a growing number of studies on the occurrence and effects of marine debris in the open ocean have provided a greater, yet still incomplete, understanding of this vast problem. This document characterizes marine debris in the North Pacific Gyre and identifies data gaps in the existing literature.

2.0 NATURE OF MARINE DEBRIS

2.1 Definition

Marine debris is any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment (NOAA 2010).

2.2 Types of Marine Debris

Marine debris may consist of plastic, glass, metals, styrofoam, rubber, derelict fishing gear and derelict vessels. Plastics are the predominant type of marine debris in the Pacific Gyre; plastic represents between 60% and 80% of the total marine debris in the world's oceans (Gregory and Ryan 1997).

2.3 Sources of Debris

The primary source of marine debris is the improper waste disposal or management of trash and manufacturing products, including plastics (e.g., littering, illegal dumping) (Barnes et al. 2009). Numerous studies and reviews have shown the accumulation of plastics along the world's shorelines (Ryan et al. 2009, Boland and Donohue 2003, Dameron et al. 2007, Frost and Cullen 1997, Costa et al. 2009); however it is difficult to identify specific sources due to the fragmentation and degradation of debris deposited on the shorelines.

From 2001 to 2006, the National Marine Debris Monitoring Program (NMDMP) analyzed marine debris deposited on beaches monitored along the west coast of the United States (i.e., Washington, Oregon, and California) and on the main Hawaiian Islands to characterize sources of debris and estimate the relative contribution of debris observed on beaches (Table 1). In general, sources of marine debris are either land-based and/or from fishing activities (Frost and Cullen 1997, Sheavly 2007). Debris is generated on land at marinas, ports, rivers, harbors, docks, and storm drains. Debris is generated at sea from fishing vessels, stationary platforms and cargo ships (Day et al. 1989, Morishige et al. 2007, Pichel et al. 2007).

Table 1. Relative Breakdown of Marine Debris Sources for the West Coast and Hawaii (Sheavly 2007)

Study Region	Land-Based Indicator Items	Ocean-Based Indicator Items	General* Indicator Items
West Coast of the United States	54%	11%	35%
Main Hawaiian Islands	22%	43%	35%

** The general category represents types of marine debris that originate from unspecified land-based or ocean-based sources.*

Limited research indicates that much of the land-based pollution originates in the Western Pacific (Day et al. 1989). According to the International Coastal Cleanup report, the most common items found during clean-ups conducted onshore and/or underwater include: cigarettes/cigarette filters, food wrappers/containers, (plastic) bags, and (plastic) beverage bottles (Ocean Conservancy 2007). The California Coastal Commission found that plastic bags comprise 13.5% of shoreline litter; the City of Los Angeles found that plastic bags made up 25% of litter in storm drains (City of Los Angeles et al. 2003). Data from the California Department of Transportation (Caltrans) found that polystyrene makes up 15% of storm drain debris (California Integrated Waste Management Board, 2004). Unlike the International Coastal Cleanup Report, bottles and cans make up a very small portion of beach debris in California, likely due to the California Bottle Bill (Container Recycling Institute 2010). The most commonly found items on beaches in Orange County, California are plastic pellets (17% by weight), expanded polystyrene, and other plastic food and beverage containers (Moore et al. 2001). In the Northwestern Hawaiian Islands – Marine National Monument (NWHI-MNM) approximately 52 metric tons of derelict fishing gear accumulate annually (Dameron et al. 2007).

Ninety-six percent of the plastic found in the North Pacific was small pieces of plastic (Robards et al. 1997) demonstrating that the North Pacific has more neuston plastic than other oceans. Such debris is composed of fragments of manufactured plastic products (user plastic), and pre-production plastic pellets (industrial pellets, virgin pellets, plastic resin beads, or nurdles) that are shipped from manufacturing plants to plastic injection factories to be melted and molded into consumer products (Derriak 2002).

2.4 Data Gap

Analyses of plastic debris in the environment derived from beach-cleaning surveys typically only provide data on coarse trends and larger items (Barnes et al. 2009). In order to gain an accurate and meaningful assessment of plastics and their influence, large-scale and long-term monitoring is needed across countries and environments, including the sea floor, and across a range of debris sizes. Debris sizes can broadly be divided into the following generally accepted categories: macro-debris (>20 mm diameter), meso-debris (5–20 mm) and micro-debris (<5 mm). The term mega-debris (>100 mm) is also used and can be applied to large debris items such as derelict fishing nets (Barnes et al. 2009).

3.0 EXTENT OF MARINE DEBRIS IN THE PACIFIC GYRE

3.1 Location

Marine debris in the Pacific Gyre consists of high densities of floating plastic debris, particularly between 20^{o}N and 40^{o}N latitude, within a few hundred miles of the coast and in the gyre centers, between the tropical and subarctic waters. This area of concentrated debris consists of two accumulations: the “Western Garbage Patch” that occurs off Japan and “Eastern Garbage Patch” residing between Hawaii and California that correspond to the locations of two sub-gyres within the Pacific Gyre, connected by a narrower band of marine debris north of the Hawaiian archipelago (Young et al. 2009) (Figure 1).

The sizes of the marine debris patches are difficult to determine because they are ever expanding and moving; distribution and quantities of debris are not well quantified. The patches are estimated to contain approximately 100 million tons of garbage; most of the debris is found just below the water surface and extending down to depths of 100 feet or more, and is not tightly packed (Dautel 2009).

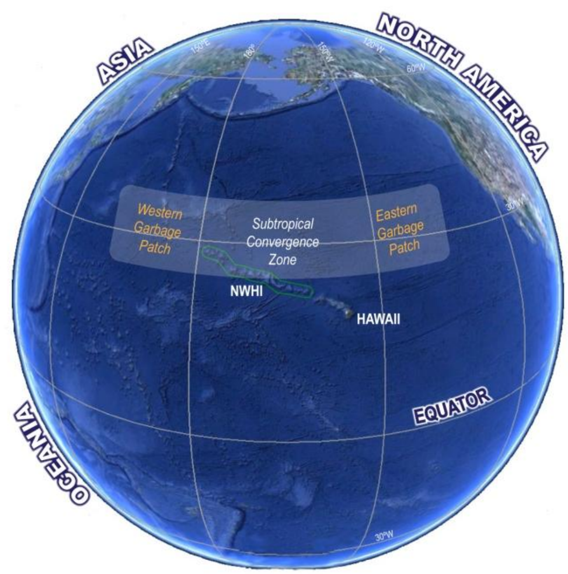

Figure 1. Generalized Illustration of STCZ and Garbage Patch Locations

Satellite remote sensing data, aircraft observations and ocean circulation models have been used to detect derelict nets and other debris in the open ocean. Ocean circulation and wind-drift models suggest that debris in the North Pacific would tend to concentrate along a southwest-to-northeast line north of the Hawaiian Islands that coincides with the Subtropical Convergence Zone (STCZ). In the central North Pacific, the STCZ is located between 23°N and 37°N latitude, seasonally migrating between these extremes (Pichel et al. 2007). The islands and atolls of the Hawaiian Archipelago stretch 1500 km from 19°N to 28°N latitude and act as a filter, garnering marine debris from passing currents (Donohue et al. 2001) (Figure 2).

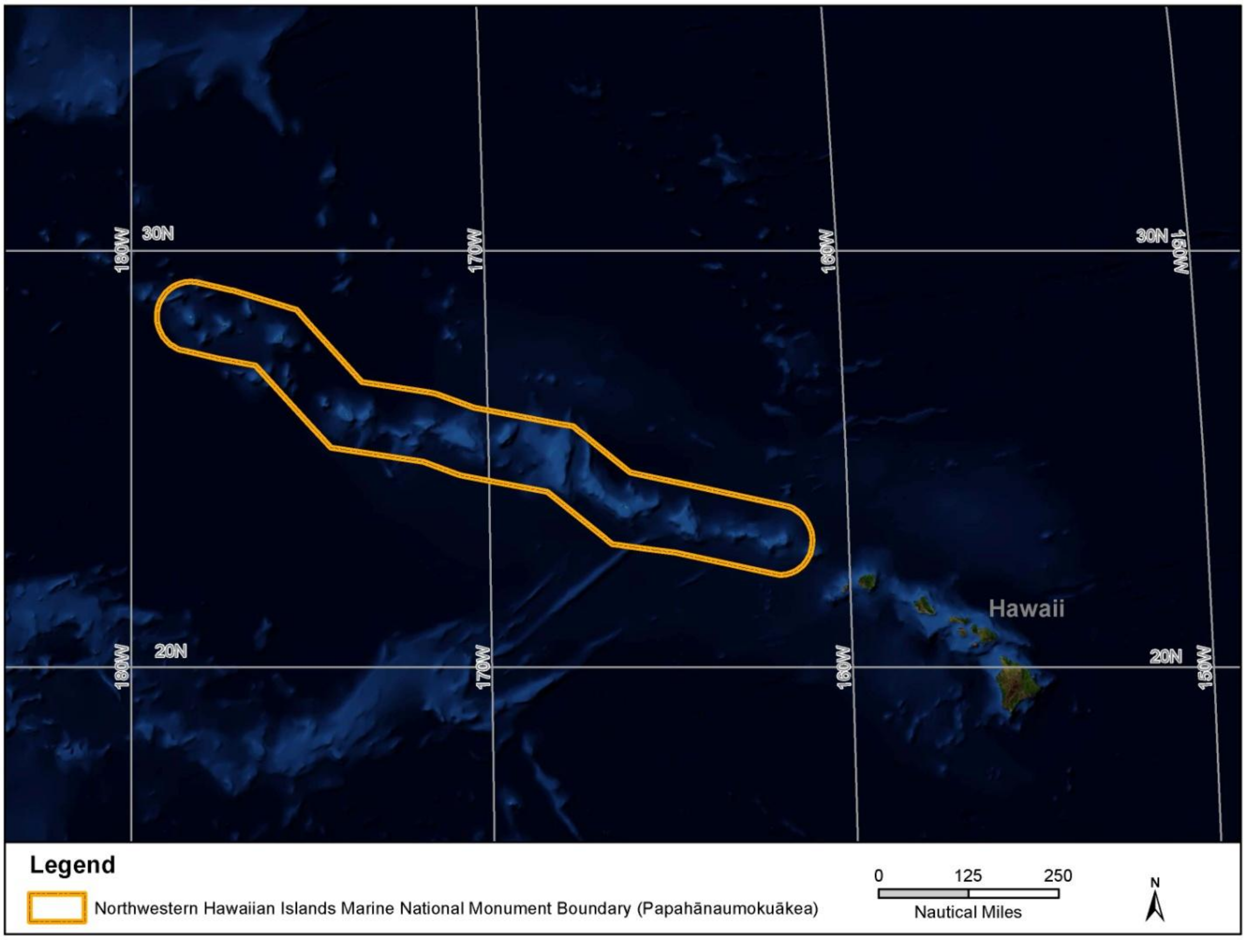

Figure 2. Location of Northwestern Hawaiian Islands Marine National Monument

3.2 Depth Within the Water Column

Vertical transport of plastics is complex and requires an understanding of the biophysical and chemical processes that contribute to plastic breakdown and buoyancy (Ye and Andrady 1991). Approximately half of all plastics are neutrally to positively buoyant (USEPA 1992) and thus remain close to the ocean surface. With time, and as the plastic breaks down into smaller pieces, organism and sediment fouling adds weight to the particles and can cause the plastics to sink and eventually reach the seabed (Barnes et al. 2009). The other half of plastics are negatively buoyant and sink within the water column until neutral buoyancy or the sea floor is reached. Most studies have explored plastic accumulation from the ocean surface down to a depth of approximately 30m (100 feet) (Moore et al. 2005).

3.3 Density of Plastic Debris

Studies provide highly variable estimates of marine debris density in the near-surface zone and encompass five orders of magnitude (from less than 1 item per square km to as many as 332,556 items per square kilometer) (NRC 2008). The highest densities (number per square kilometer) and concentrations (gram per square kilometer) of neuston plastic, which is plastic that floats at or slightly below the water surface, from all oceans studied occurred in the Japan Sea/nearshore Japan Water, in Transitional Water, and in Subtropical Water (Day et al. 1989).

Studies based on satellite-derived information and ocean circulation models, and confirmed by flight observations, show that the largest debris concentration in the North Pacific is found just north of the North Pacific Transition Zone Chlorophyll Front (TZCF) within the North Pacific STCZ. Debris densities appear to be significantly correlated with sea-surface temperature and chlorophyll-a concentration (Pichel et al. 2007). The study which determined this correlation was limited to in-flight observations of macro-debris size plastics. In 2005, a study conducted by Airborne Technologies, Inc. and the US Department of Commerce, National Oceanic and Atmospheric Administration's (NOAA) Fisheries Service documented marine debris in the STCZ utilizing satellite imagery, confirming the STCZ contains high densities of marine debris (Morishige et al. 2007).

3.4 Data Gap

Few studies have attempted to quantify the abundance and mass of neustonic debris in situ, perhaps because shiptime for extensive open ocean trawls are costly and time-consuming (Fan 1997). More studies are needed to correlate marine debris accumulations with currents and shipping lanes to determine the fate and transport of debris—sources and destinations—to target clean up and prevention efforts. Consistent monitoring and sampling methodologies are needed in order to compare results between studies over time. Also, studies based on satellite-derived information and ocean circulation models, and confirmed by flight observations, will help provide a consistent method of integrated assessment.

4.0 PHYSICAL TRANSPORT MECHANISMS

As discussed above, the introduction, or contribution, of marine debris to the coastal zone and ocean may come from a variety of sources. Debris may be transported from inland areas to the coastal zone via a combination of mechanisms such as wind, stormwater conveyances and streams and rivers. Models developed by Martinez et al. 2009 suggest marine debris deposited in the coastal zone tends to accumulate in the central oceanic gyres within two years after deposition. The transport mechanisms of marine debris can be divided into two categories: 1) the mechanisms that contribute marine debris to the ocean; and 2) the mechanisms that transport marine debris throughout the ocean.

4.1 Wind and Current Models

Several studies have identified the primary transport mechanisms by which marine debris accumulates in the convergence zones of the world's oceans (Kubota 1994, Martinez et al. 2009, and Ingraham and Ebbesmeyer 2000). These mechanisms are a combination of Ekman transport and geostrophic currents, and to a lesser degree, Stoke's drift. Ekman transport is a wind-driven ocean current, and has a net transport at right angles to the direction of the prevailing winds in the Northern Hemisphere (Pond and Pickard 1983). In the North Pacific, the prevailing wind patterns are the Northeast Trade winds blowing generally from east to west in the low latitudes and the westerlies (blowing from west to east in the mid-latitudes).

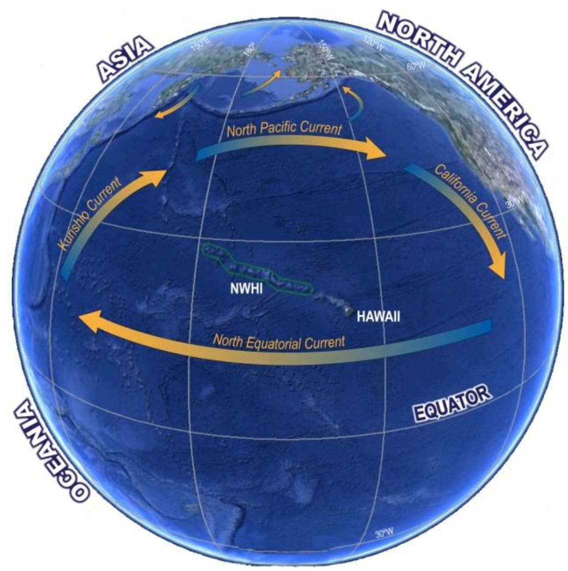

Figure 3. Generalized Illustrations of Primary Geostrophic Currents in the North Pacific

Geostrophic currents are ocean currents that travel at right angles to horizontal pressure gradients (from high to low pressure) (Brown et al. 1989). In the North Pacific, high pressure dominates the mid-latitudes; therefore, the geostrophic flow pattern becomes clockwise around this high pressure, flowing westward in the low latitudes (North Pacific Equatorial Current), northward in the west (Kuroshio Current), eastward in the higher latitudes (North Pacific Current), southward in the east (California Current). Stoke's drift is the net transport of water in the direction of wave travel (Pond and Pickard 1983) (Figure 3).

The coupling of these atmospheric and oceanographic processes creates the North Pacific STCZ. The STCZ is located north of the Hawaiian Islands between the mid-latitude westerlies and the easterly trade winds. The STCZ migrates between 23°N and 37°N with changes in atmospheric high pressure (Pichel et al. 2007).

4.2 Debris Accumulation Models

Both Kubota (1994) and Martinez et al. (2009) developed models to predict the accumulation of marine debris in the subtropical gyres. Although Kubota studied the North Pacific and Martinez studied the South Pacific, their results were in agreement. In Kubota (1994), the effects of Ekman transport, Stoke's drift and geostophic currents were combined to model the transport of marine debris. This effort resulted in a significant concentration of markers north of Hawaii in the mid-latitudes. Kubota (1994) suggested the results illustrated a three step process:

1) Marine debris converges in mid-latitude zone by Ekman transport associated with easterly trade winds and westerly winds in upper latitudes.
2) Accumulated marine debris in the mid-latitude zones is transported eastward due to geostrophic currents (i.e., North Pacific Current, Subarctic Current).
3) Marine debris becomes concentrated north of Hawaii due to subtropical high and Ekman transport (zone of convergence).

Kubota (1994) showed that Ekman transport strongly influences the accumulation of debris in the STCZ. Since Ekman transport and geostrophic currents in the subtropical gyre become extremely weak, marine debris can reside in this convergence zone for a long residence time. He also modeled that the STCZ moves seasonally (north in the summer, and south in the winter) which correlates with the movement of the North Pacific Subtropical High.

Martinez et al. (2009) also evaluated the effect the El Nino/Southern Oscillation (ENSO) climate pattern may have on accumulation of marine debris. During El Nino years, the accumulation of plastics in convergence zone is reduced due to decreasing or a reversal of the trade winds. Conversely, during La Nina years, which are characterized by increasing trade winds, the accumulation of plastics in the convergence zone was greater. Although El Nino/La Nina conditions affect the rate of convergence of marine debris, the long-term trends of marine debris accumulating in the South Pacific Subtropical Gyre were not significantly affected.

Since the mechanisms described above influence the transport of both marine debris and planktonic organisms (drifters) similarly, satellite-derived measurements of chlorophyll-*a* can be used to predict areas where marine debris accumulates. Pichel et al. (2007) examined the method of using the TZCF as an indicator for the STCZ. The results showed a significant correlation of marine debris with sea surface temperature (SST), chlorophyll-*a*, and the chlorophyll-*a* gradient; therefore, the TZCF could be used as an indicator for the location of the STCZ. The co-occurrence of marine debris with phytoplankton, zooplankton and other drifters within these convergence zones increases the potential impacts of marine debris on higher trophic level species, such as loggerhead turtles and albacore tuna, which have been shown to preferentially forage within the TZCF (Polovina et al. 2001).

The occurrence and transport mechanisms of marine debris in the surface waters and coastal habitats of the North Pacific are well documented. Unfortunately, due to the logistics of sampling the substrate in deep waters, the occurrence of marine debris on the seafloor is less known. However, studies by Watters et al. (2010), Galgani et al. (1996) and Ryan et al. (2009) have shown the accumulation of marine debris in bottom sediments. Biofouling of plastic debris in the surface waters may alter the buoyancy of the plastic, resulting in sinking and deposition on the seafloor (Teuten et al. 2007).

4.3 Marine Debris and Persistent Organic Pollutants

The transport of marine debris, specifically plastics, is itself a mechanism for transport of persistent organic pollutants (POPs). Plastics are man-made polymers that may contain other organic pollutants such as phthalates, organotins, and phenols, including bisphenol A (BPA) (Teuten et al. 2009, Rios et al. 2010). Artham and Doble (2009) showed biodegradation of plastic polymers by bacteria introduced BPA into seawater.

In addition, plastics tend to have high affinity for the sorption of hydrophobic compounds (polycyclic aromatic hydrocarbons [PAHs], polychlorinated biphenyls [PCBs] and chlorinated pesticides) (Teuten et al. 2007, Teuten et al. 2009, Frias et al. 2010). For example, Frias et al. (2010) examined sediment samples collected from the shoreline in Portugal and found all plastic pellets contained concentrations of PAHs, PCBs, and dichlorodiphenyltrichloroethane (DDT). Similarly, Rios et al. 2007, analyzed samples of plastic debris collected from the North Pacific and coastal Hawaii and California and also found concentrations of PAHs, PCBs, and DDT. Frias et al. (2010) suggest that the entire food chain may be impacted due to the pervasive nature of plastics and their widely accepted use.

4.4 Data Gaps

While much is known about the large-scale oceanographic dynamics that affect plastic accumulation in the Pacific as well as the physical impacts of plastic debris on larger conspicuous marine and seabird species, there are a still a number of data gaps relating to smaller spatial scale dynamics that affect plastic movement and accumulation as well as impacts on plastic debris on less conspicuous species at the base of the marine food chain and impacts on humans. This information will be important for prioritizing and implementing clean-up efforts since environmental and human health risks and technical feasibility of mitigation options will need to be jointly considered.

In regards to oceanographic processes, further studies are needed to determine the relationship between the differing sizes and densities of plastic marine debris and transport dynamics. Although a study by Su et al. (1993) suggested a segregation of marine debris may be anticipated based on size and density of the debris, similar studies should be conducted at larger spatial and temporal scales in order to relate the results to the transport of marine debris in the North Pacific. There is little empirical data to show if debris of different sizes accumulate in different zones within the oceans. Additionally, very little is known about the accumulation and density of plastics on the sea floor, especially at greater depths. Given the environmental uniqueness of the NWHI-MNM and high risk of marine plastic debris to associated marine habitats and species, studies are needed to better understand the flux of plastics into and out of the region. Understanding plastic transport dynamics will be crucial for selecting different mitigation strategies, since both risk factors and clean up options are dependent on the size, density, and location of the debris.

5.0 ENVIRONMENTAL IMPACTS

Marine debris travels throughout the world's oceans, accumulating on beaches and within gyres, and this debris can degrade physical habitats, transport chemical pollutants, threaten marine life, and interfere with human uses of marine and coastal environments. Plastic marine debris is considered to have the greatest potential to alter the environment and impact biota and humans, since it floats at the surface, is widely transported by ocean currents, persists in the environment for years, and is not readily digestible when consumed. Therefore, the impact of plastic marine debris is much more than a mere aesthetic problem.

5.1 Physical Habitat Impacts

Physical habitat alteration is caused by the accumulation of debris in oceanic convergence zones, on beaches, and submerged benthic habitats. As debris accumulates, habitat structure may be modified, light levels may be reduced in underlying waters, and oxygen levels may be depleted. These changes can undermine the ability of open water and benthic habitats to support marine life.

Accumulations of marine debris along the benthos can result in habitat degradation due to smothering, abrasion, and fragmentation of sensitive habitats and habitat forming species, such as macroalgal beds and coral reefs (Donohue et al. 2001, Asoh et al. 2004, Chiappone et al. 2005). Derelict fishing gear, including nets and lines, can settle on coral reefs as currents and waves transport them to shallow habitats. As the debris accumulates, it can entangle branching species of corals resulting in fragmentation and abrasion, potentially reducing habitat heterogeneity and providing open substrate for macroalgal colonization. Additionally, plastic marine debris can smother the benthos, reducing light penetration and oxygen exchange (Goldberg 1994, Uneputty and Evans 1997).

As benthic habitat-forming species decline and as the physical structure of the habitats are modified, indirect impacts of marine debris may cause declines in species that are dependent on the habitats for foraging and shelter. For example, degradation of coral reefs globally has the potential to undermine the survival of a diverse array of invertebrates, fish, and vertebrates that depend on this limited resource, including a number of threatened and endangered species.

5.2 Chemical Impacts

Chemical impacts associated with plastic marine debris include the accumulation and transport of POPs, such as PCBs and pesticides. Marine plastic debris has been found to accumulate contaminants at concentrations that are orders of magnitude greater than the surrounding environment (Rios et al. 2007). In a study of contaminant levels in plastic pellets collected globally, the highest PCB concentrations in plastics occurred in areas with the highest production and use patterns, as well as concentrations in the environment (Teuten et al. 2009). Additionally, marine plastic fragments collected from a beach near Tokyo, Japan and from the North Pacific Gyre (approximately 1000 km from the U.S. west coast) were also found to contain PCBs, DDE, PAHs, as well as other organics (Teuten et al. 2009). Based on these studies, it is apparent that plastics have the potential to adsorb chemicals of concern from the environment, and serve as a potential global transport mechanism for contaminants of concern.

Contaminants can be released from plastics to the environment and biota by the breakdown of plastics through ultraviolet (UV) radiation, mechanical forces, and weathering, as well as by ingestion by biota. Evidence is beginning to mount that plastic debris, including resin pellets and fragments, transfer POPs to organisms when consumed. For example, the accumulation of POPs from plastics has been documented in seabirds (Ryan et al. 1988), and benthic organisms (Teuten et al. 2009). In the case of the great shearwater (*Puffinus gravis*), a positive correlation was observed between the mass of ingested plastics and the PCB concentrations in fat tissues (Ryan et al. 1988).

5.3 Biological Impacts

There is a substantial body of evidence documenting the deleterious effects of marine plastic debris on marine biota (reviewed by Goldberg 1995, Derraik 2002). It has been estimated that plastic marine debris adversely affects 267 species globally, including 86% of sea turtles, 44% of seabirds, and 43% of marine mammals (Laist 1997). The most common threats to biota include ingestion and entanglement (Laist 1987, 1997, Quayle 1992).

5.3.1 Ingestion

Ingestion of plastic debris by seabirds (Shaw and Day 1994), fish (Carpenter et al. 1972), and sea turtles (Gramentz 1988) has been widely documented, and incidences of ingestion have been reported for marine mammals as well (reviewed by Laist 1997). The potential for plastic ingestion is largely associated with foraging strategies and prey types. For example, planktivorous birds consume more plastics than do piscivores (Azzarello and Van Vleet 1987), and sea turtles readily consume plastic bags and other floating debris that appear similar to their gelatinous prey (Balazs 1985, Bugoni et al. 2001, Bjorndal et al. 1994, and Tomas et al. 2002). Additionally, predatory organisms, such as fur seals, may indirectly consume plastics through consumption of pelagic fish and other prey (Eriksson and Burton 2003).

Problems associated with the ingestion of plastics include development of internal and external wounds, impairment of feeding capacity due to the buildup or blockage of the digestive system, decreased mobility and predatory avoidance, and toxicity (reviewed by Gregory 2010). Ingestion of plastics by seabirds has been shown to reduce body weight (Spear et al. 1995), inhibit fat deposition (Connors and Smith 1982), and reduce reproductive capacity (Azzarello and Van Vleet 1987). Additionally, the deaths of sea turtles, whales, manatees, and dolphins have been attributed to gastrointestinal blockages by plastics (reviewed by Derraik 2002, Gregory 2010).

Studies have shown a rise in plastic ingestion since the 1980s (Blight and Burger 1997). The number of marine animals impacted by plastic may be highly underestimated as most victims are likely to go undiscovered over vast ocean areas, as they either sink or are eaten by predators (Wolfe 1987).

5.3.2 Entanglement

Marine debris entanglements have been documented for 135 species of invertebrates, fish, seabirds, sea turtles, seals, sea lions, dolphins, and whales (Laist 1997), with many species experiencing injury and even mortality (reviewed by Derraik 2002). One of the greatest threats of entanglement to marine life and seabirds is derelict fishing gear, including monofilament line, trawl nets, and gill nets. Lost and free floating fishing gear can continue to ―ghost fish" for months and even years, ensnaring a wide range of species, particularly in areas adjacent to fishing grounds, along current convergence zones, and along shorelines where debris is deposited by currents and waves.

5.4 Threatened and Endangered Species

There are a number of documented impacts of marine debris on Endangered Species Act (ESA) – protected species throughout the Hawaiian archipelago, the Pacific, as well as the world (Laist 1997). Within the Pacific Gyre, the accumulation of plastic debris within the waters and on the shorelines of the NWHI-MNM is of particular concern due in part to the presence of 13 marine species that are listed as threatened or endangered under the ESA (Table 2).

Table 2. Threatened or Endangered[1] Marine Species Occurring in the NWHI-MNM

Common Name	Species	Listing
Marine Mammals		
Hawaiian monk seal	*Monachus schauinslandi*	E
Humpback whale	*Megaptera novaengliae*	E
Sperm whale	*Physeter macrocephalus*	E
Blue whale	*Balaenoptera musculus*	E
Fin whale	*B.physalus*	E
Sei whale	*B.borealis*	E
North Pacific right whale	*Eubalena japonica*	E
Marine Turtles		
Olive Ridley turtle	*Lepidochelys olivacea*	T/E
Leatherback turtle	*Dermochelys coriacea*	E
Loggerhead turtle	*Caretta caretta*	T
Hawksbill turtle	*Eretmochelys imbricate*	E
Green turtle	*Chelonia mydas*	T
Seabirds		
Short-tailed albatross	*Phoebastria albatrus*	E

Notes:
1. Under the Endangered Species Act of 1973 and the State of Hawaii (HRS 195D), endangered species are those in danger of extinction. Threatened Species are those likely to become an endangered species within the foreseeable future.
E = endangered; T = Threatened. (NOAA; USFWS; HIDLNR 2008).

5.4.1 Hawaiian Monk Seals

The Hawaiian monk seal, *Monachus schauninslandi*, is one of the rarest marine mammals in the world, and is the only marine mammal that is endemic to the Hawaiian Islands. Hawaiian monk seals predominantly inhabit the waters surrounding atolls, islands, reefs, and submerged banks of the NWHI-MNM. They breed and haul-out on sand, corals, and volcanic rock, and preferentially pup on sandy protected beaches surrounded by shallow waters (NOAA 2011). Entanglement by marine debris, particularly derelict fishing gear, is one of the greatest threats to the Hawaiian monk seal (Henderson 2001, Boland and Donahue 2003). Between 1982 and 1988, there were 173 documented entanglements occurring in the NWHI-MNM, with 28 resulting in injuries, including 7 seals found dead and 8 instances where entangled seals were never observed again. (Henderson 1990, 2001). In light of the extremely small population size of the Hawaiian monk seal, the observed rate of entanglement (0.70%) appears to be a significant threat to the species.

5.4.2 Sea Turtles

All 7 of the world's sea turtles are listed as either threatened or endangered, including the five sea turtles found in U.S. Pacific Ocean waters: green sea turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys impricata*), leatherback turtle (*Dermochelys coriacea*), loggerhead turtle (*Caretta caretta*), and olive ridley turtle (*Lepidochelys olivacea*) (NOAA 2011). Sea turtles largely occur within tropical and subtropical waters, with several of the species occurring circumtropically, including within the Pacific Convergence Zone. A number of these species (e.g., leatherbacks, juvenile loggerheads, and juvenile green turtles) spend at least a portion of their lives feeding within the pelagic convergence zones on planktonic organisms, often in areas where floating plastic debris also accumulates. Sea turtles do not appear to distinguish between floating debris and floating prey, resulting in ingestion of plastic bags and sheets (Lutz 1990), as well as entanglement in monofilament lines, nets, and other plastic debris (Balazs 1985). As such, observations of entanglement and ingestion of marine debris has been reported for all species of sea turtles that inhabit U.S. waters, with 5% of approximately 1500 sea turtles observed to be entangled at sea globally (Laist 1997). Entanglements have resulted in deaths, gangrenous flippers, and the need for human intervention to free animals (Balazs 1985). Ingestion of plastic debris has been observed to block the esophagus, potentially impeding feeding and resulting in death (Gregory 2010).

5.5 Human Impacts

In addition to degrading the habitats and ecosystem services that humans use, plastic marine debris can directly interfere with navigation, impede commercial and recreational fishing, threaten health and safety, and reduce tourism (NOAA 2008). Large debris, such as derelict fishing nets and lines that float at or just below the surface, pose the greatest threat to vessel navigation. Lines and nets can become wrapped around propellers and entrained in intakes of motors, and vessels may strike large items, damaging hulls and propellers. Immobilization of commercial and recreational vessels can result in increased cost of navigation due to lost time, costly repairs, as well as the loss of human life. In a tragic example, derelict fishing gear contributed to the sinking of a Korean passenger ferry in 1993 that resulted in the deaths of 292 passengers (Cho 2006).

Humans can also be directly impacted by marine debris, becoming entangled in nets and lines while swimming or being injured by sharp debris that accumulates on beaches. It is not uncommon for SCUBA divers to become entangled in nets or lines. In most instances they are able to free themselves; however, in rare instances entanglement has resulted in injury and even death (NOAA 2008). Additionally, sharp debris that accumulates on beaches regularly result in punctures and lacerations. Medical waste, such as hypodermic needles, is of particular concern because punctures can result in the transfer of infections and disease. Due to the human health risk of medical debris, beaches in New York and New Jersey were closed to protect the public from medical waste that washed ashore in 1988. It was estimated that the loss of revenue from beach closures in 1988 to New Jersey alone was in the range of $706 million to nearly $3 billion (Ofiara and Brown 1999).

Not only does the accumulation of debris pose a human health risk, but it also reduces the aesthetic and recreational values of beaches and marine resources. The buildup of plastic debris on beaches is of particular concern for coastal cities, since unsightly debris, and the distressing sight of entangled marine life and seabirds can reduce the area's attractiveness to local residents and tourists (Gregory 2010). As a result, immense economic costs are incurred to clean marine debris from beaches.

Ironically, fishing gear that is lost or discarded at sea may have the greatest impact on humans due to impediments to commercial and recreational fishing. Similar to other vessels, fishing vessels are subject to entanglement of propellers by nets and lines, resulting in the loss of opportunities to fish and increased costs of repairing vessels. For example, the Japanese fishing industry estimated that $4.2 billion was spent on repairing vessels damaged by marine debris in 1992 (NOAA 2008). Additionally, ghost fishing by lost nets and pots can remove fish and invertebrates that are targeted by local commercial and recreational fisheries. It was estimated that derelict crab pots capture approximately 200,000 pounds of Dungeness crab in Puget Sound annually, which would have commanded a market value of $335,000. Therefore, ghost fishing can compete with active fishing for limited resources, undermining economic opportunities while also decreasing the reproductive capacities and viabilities of fish and invertebrate stocks (NOAA 2008).

5.6 Data Gap

The effects of small-plastic debris on marine animals, including toxicity of pellets and fragments that wash up on beaches throughout the Hawaiian Archipelago, remains unknown but should be investigated (McDermid and McMullen 2004). The Interagency Report on Marine Debris Sources, Impacts, Strategies and Recommendations released by the Interagency Marine Debris Coordinating Committee (IMDCC) in August 2008 highlights the many data gaps that exist with respect to understanding the sources and impacts of marine debris as well as a lack of comprehensive and coordinated voluntary and regulatory tools to address the problem (NOAA 2008). This Congressional report fulfilled a requirement of the Marine Debris Research, Prevention and Reduction Act, 33 U.S.C. 1954. The report *Tackling Marine Debris in the 21 Century* (NRC 2008) is a comprehensive overview of the problem of marine debris and was compiled by the National Academy of Sciences at the behest of the IMDCC. The report examines the many areas where more information and increased coordination between local, state, federal and international parties is needed, and contains recommendations for filling some of the gaps.

Further data is also needed to assess trophic transfer dynamics of POPs via plastic throughout the marine food web. Currently, there is only a limited amount of data on the transfer of POPs from plastic marine debris to conspicuous marine organisms, such as sea birds. By studying the effects of plastics on the planktonic and benthic invertebrate communities, as well as top predators, a better understanding of potentially important and currently understudied impacts of plastics can be gained.

Trophic transfer potential also has important human health risk ramifications. Impacts to humans from consumption of fish and invertebrates that ingest plastics are in large part currently unknown. Therefore, collection of tissues from fish that comprise part of the pelagic food web will be important for understanding the potential for transfer of plastic particles and POPs to humans.

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