Chapter 25. Marine Debris

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1. Overview

1.1 Definition of marine debris

Litter disposal and accumulation in the marine environment is one of the fastest-growing threats to the health of the world's oceans (Pham et al., 2014). Marine debris, also known as marine litter, has been defined by UNEP (2009) as “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment”. Marine debris consists of items that have been made or used by people and deliberately discarded into the sea or rivers or on beaches; brought indirectly to the sea with rivers, sewage, storm water or winds; accidentally lost, including material lost at sea in bad weather (fishing gear, cargo); or deliberately left by people on beaches and shores (UNEP, 2005). In 1997, the United States of America Academy of Sciences estimated the total input of marine litter into the oceans, worldwide, at approximately 6.4 million tons per year (UNEP, 2005). Jambeck et al (2015) recently calculated that 275 million metric tons (MT) of plastic waste was generated in 192 coastal countries in 2010, with 4.8 to 12.7 million MT entering the ocean.

Marine debris is present in all marine habitats, from densely populated regions to remote points far from human activities (UNEP, 2009) from beaches and shallow waters to the deep-ocean trenches (Miyake et al. 2011). The density of marine debris varies greatly among locations, influenced by anthropogenic activities, hydrological and meteorological conditions, geomorphology, entry point, and the physical characteristics of debris items. However, a recent study presented data on detectable floating plastic accumulation with visual observation in the North Atlantic and Caribbean from 1986 to 2008, the highest concentrations (> 200,000 pieces per square kilometre) occurred in the convergence zones (Law et al., 2010). Computer model simulations, based on data from about 12,000 satellite-tracked floats deployed since the early 1990s as part of the Global Ocean Drifter Program (GODP, 2011), confirm that debris will be subject to transport by ocean currents and will tend to accumulate in a limited number of sub-tropical convergence zones or gyres (IPRC, 2008; UNEP and NOAA, (2011)) (Figure 1).

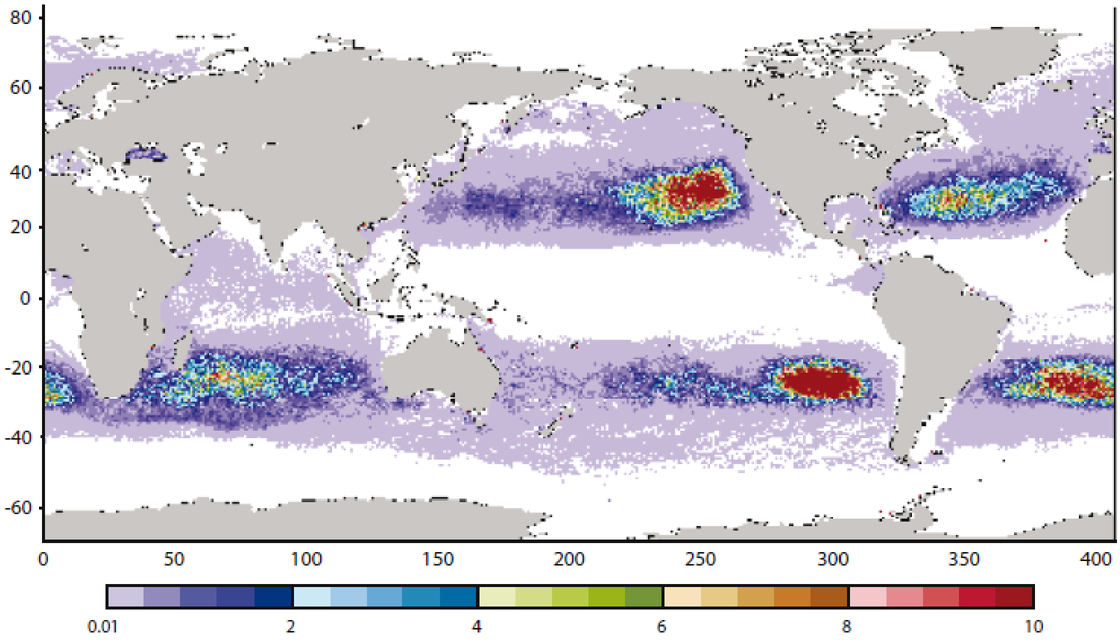

Figure 1. A model simulation of the distribution of marine litter in the ocean after ten years shows plastic converging in the five gyres: the Indian Ocean gyre, the North and South Pacific gyres, and the North and South Atlantic gyres. The simulation, derived from a uniform initial distribution and based on real drifter movements, shows the influence of the five main gyres over time. Source: IPRC, 2008.

1.2 Types of marine debris

Marine debris comprises of various material types, and can be classified into several distinct categories (ANZECC, 1996; Edyvane et al., 2004; Ribic et al., 1992; Galgani et al., 2010):

(a) ***Plastics***, covering a wide range of synthetic polymeric materials, including fishing nets, ropes, buoys and other fisheries-related equipment; consumer goods, such as plastic bags, plastic packaging, plastic toys; tampon applicators; nappies; smoking-related items, such as cigarette butts, lighters and cigar tips; plastic resin pellets; microplastic particles;

(b) ***Metal***, including drink cans, aerosol cans, foil wrappers and disposable barbeques;

(c) ***Glass***, including bottles, bulbs;

(d) ***Processed timber,*** including pallets, crates and particle boards;

(e) ***Paper and cardboard***, including cartons, cups and bags;

(f) ***Rubber,*** including tyres, balloons and gloves;

(g) ***Clothing and textiles***, including shoes, furnishings and towels.

1.3 Sources of marine debris

Marine debris originates from a wide and diverse range of sources. The majority of marine debris (approximately 80 per cent) entering the seas and oceans is considered to originate from land-based sources (Allsopp, et al., 2006), including sewage treatment, combined sewer overflows, people using the coast for recreation or shore fishing, shore-based solid waste disposal, inappropriate or illegal dumping of domestic and industrial rubbish, poorly managed waste dumps, street litter which is washed, blown or discharged into nearby waterways by rain, snowmelt, and wind, etc. The remaining can be attributed to maritime transport, industrial exploration and offshore oil platforms, fishing and aquaculture (UNEP, 2009) and loss and purposeful disposal (e.g. ballast weights made of steel, lead or cement) of scientific equipment.

2. Environmental Impacts

The incidence of debris in the marine environment is a cause for concern. It is known to be harmful to biota, it presents a hazard to shipping (propeller fouling), it is aesthetically detrimental, and it may also have the potential to transport contaminants over long distances (STAP, 2011). Marine debris, and in particular the accumulation of plastic debris, has been identified as a global problem alongside other contemporary key issues, such as climate change, ocean acidification and loss of biodiversity (CBD and STAP-GEF, 2012).

2.1 Entanglement and Ingestion

Marine debris results in entanglement of and ingestion by organisms, and poses a direct threat to marine biota. Adverse effects of marine debris have been reported for 663 species by reviewing available publications (CBD and STAP-GEF, 2012). Over half of these reports documented entanglement in, and ingestion of, marine debris, representing almost a 40 per cent increase since a review in 1997, which reported 247 species (Laist, 1997). Reports revealed that all known species of sea turtles, about half of all species of marine mammals, and one-fifth of all species of sea birds were affected by entanglement in, or ingestion of, marine debris. Species with the greatest number of individuals affected by entanglement or ingestion were the Northern fur seal, *Callorhinus ursinus*, the California sea lion, *Zalophus californianus*, and the seabird *Fulmarus glacialis*; the most frequently reported species are all either birds or marine mammals. About 15 per cent of the species affected through entanglement and ingestion are on the IUCN Red List (CBD and STAP-GEF, 2012).

Abandoned, lost or discarded fishing gear (including monofilament line, nets and ropes), as well as ropes, netting and plastic packaging, can be a cause of entanglement for pinnipeds (seals and related genera), cetaceans, turtles, sharks, sirenia (dugongs and related genera) and birds (WSPA, 2012). The effects range from immediate mortality through drowning to progressive debilitation over a period of months or years (Laist, 1997). Pinniped entanglement usually involves plastic collar-like debris which is often referred to as “neck collars”, where the plastic forms a collar around the neck. The animal cannot remove it and it hampers normal feeding or breathing (Allen et al., 2012; Waluda and Staniland, 2013). As the animal grows, the collar effectively tightens and cuts into tissues becoming firmly embedded in skin, muscle and fat (WSPA, 2012) and may cause death. “Ghost fishing” as it is known, can affect many species of fish and invertebrates such as crabs, corals and sponges. For example, several dead and moribund Geryon crabs were found associated with discarded nets in the deep Mediterranean (Ramirez-Llodra et al., 2013). In addition, lost and abandoned traps and the associated by-catch are a global issue with annual trap loss rates approaching 90 per cent in some fisheries (Al-Masroori et al. 2009; Bilkovic et al. 2012).

Marine debris can be mistaken for food items and be ingested by a wide variety of marine biota (Pham et al., 2014). Many species of seabirds, marine mammals and sea turtles have been reported to eat marine debris. Ingestion of sharp debris may damage their guts and result in infection, pain or death. Plastic polymer mass may irritate the stomach tissue, cause abdominal discomfort, and stimulate the animal to feel full and cease eating (Derraik, 2002; Galgani et al., 2010). Two sperm whales (*Physeter macrocephalus*) were found off the coast of northern California in 2008 with a large amount of fishing gear in their gastrointestinal tracts (Jacobsen et al., 2010). A total of 141 mesopelagic fishes from 27 species in the North Pacific Subtropical Gyre, were dissected to examine whether their stomach contents contained plastic particles. The incidence of plastic in fish stomachs was 9.2 per cent (Davison and Ash, 2011). The study of planktivorous fish from the North Pacific gyre found an average of 2.1 plastic items per fish (Boerger et al., 2010). However, the consequences of ingestion are not fully understood, because effects associated with ingestion can mostly be determined by necropsy (CBD and STAP-GEF, 2012; Hong et al., 2013).

2.2 Transport of chemicals

Plastics have a wide variety of chemicals, including those from manufacturing and those that accumulate from the marine environment (i.e. ambient seawater).

Plastics contain a wide variety of potentially toxic chemicals incorporated during manufacture which could be released into the environment (Lithner et al, 2011). Research has established that chemicals used in some plastics, such as phthalates and flame retardants, can have toxicological effects on fish, mammals and molluscs (STAP, 2011). Experimental studies show that phthalates and bisphenol-A (BPA) affect reproduction in all the species studied, impairing development in crustaceans and amphibians, and generally inducing genetic aberrations (Teuten et al., 2009).

There is recent evidence that large concentrations of microplastic and additives can harm ecophysiological functions performed by organisms (Browne et al., 2013; Wright et al., 2013).

Because of their small size, microplastics (<1 mm) have a large ratio of surface area to volume that promotes adsorption of chemical contaminants to their surface, and therefore have a high capacity to facilitate the transport of contaminants. An estimated amount of about 35,000 tons, of microplastics are floating in the world's oceans (Cozar et al. 2014; Eriksen et al. 2014). Boerger et al. (2010) found that 35 per cent of the fish sampled in the North Pacific central gyre revealed microplastics in the gut. A range of marine biota are reported to have ingested microplastics, including zooplankton (Cole et al., 2013), amphipods, lugworms and barnacles (Thompson et al., 2004), mussels (Browne et al., 2008), decapod crustaceans (Murray and Cowie, 2011), fish (Boerger et al., 2010; Rochman et al., 2013) and seabirds (Tanaka et al., 2013; van Franeker, 2011). Ingestion of microplastics has caused more and more concern in recent years, as it can provide a pathway for long-distant transport and bioaccumulation of contaminants, and may be compounded by plastic microbead additives in many personal care products (Fendall and Sewell 2009, Kershaw and Leslie 2012).

Plastic debris can accumulate persistent, bio-accumulative and toxic substances (PBTs) that are present in the oceans from other sources, such as PCBs, PAHs, DDTs and HCHs (Mato et al., 2001; Ogata et al., 2009). Within a few weeks these substances can become concentrated on the surface of or in plastic debris by orders of magnitude more than in the surrounding water column (Mato et al., 2001; Teuten et al., 2009; Hirai et al., 2011; Rios et al., 2010). Japanese medaka (*Oryzias latipes*) exposed to a mixture of polyethylene with chemical pollutants absorbed from the marine environment, bioaccumulate these chemical pollutants and suffer liver toxicity and pathology (Rochman et al., 2013). Plastics may provide a mechanism to facilitate the transport of chemicals to remote, pristine locations where they are ingested by biota (Teuten et al., 2007; Hirai et al.,2011). However, it is not yet clear whether chemicals accumulated on plastic debris are effectively transferred to marine biota (Gouin et al., 2011; Koelmans et al., 2013a and b).

2.3 Habitat Destruction

Marine debris can cause destruction of habitats in a number of ways, including smothering, entanglement, and abrasion. The extent of the impact depends on the nature of the debris (i.e., size, quantity, composition, persistence) and the susceptibility of the affected environment (i.e., habitat vulnerability and resilience).

In spite of the growing number of studies documenting the distribution and abundance of marine debris, the ecological impacts, including effects on habitats, are not well documented (NRC, 2009). The few studies that do exist looked at the impacts of derelict fishing gear (that is, gear that has been abandoned, lost or discarded) on coral reefs and other structurally complex benthic communities (Bauer et al., 2008). For example, in the Florida Keys, USA, Chiappone et al. (2005) found that 87 per cent of all debris was recreational hook-and-line fishing gear, but because of low debris density, less than 0.2 per cent of the sessile species were affected. However, Lewis et al. (2009) noted that lost lobster traps, upwards of 100,000 of which are lost each year, represent a significant threat to seagrass beds and coral reefs in the Florida Keys, especially during storms. Also, when gear and other marine debris wash up on shore, especially during storms, they can cause shoreline destruction and smother the underlying substrate where the debris comes to rest.

Although studies of the effects of marine debris on habitat have focused mainly on benthic environments, the presence of floating debris can similarly undermine the quality of pelagic habitats by: (i) affecting the mobility of species, either through entanglement or ghost fishing (that is, entangling fish in lost, abandoned or discarded fishing nets, traps or pots); (ii) reducing the quality of food available in the environment through accidental ingestion of the debris, which may have accumulated toxins on its surface and interfere with digestion and excretion; and (iii) altering the behaviour and fitness of species, as in the case of debris acting as a fish-aggregating device (Hallier and Gaertner, 2008; Hammer et al., 2012; NRC, 2009).

Abandoned and derelict vessels are a widespread problem for the marine environment. Besides the fact that sunken, stranded, and decrepit vessels can be an eyesore and become hazards to navigation, these vessels can pose significant threats to natural resources. They can physically destroy sensitive marine and coastal habitats, sink or move during coastal storms, disperse oil and toxic chemicals still on board, become a source of marine debris, and spread derelict nets and fishing gear that entangle and endanger marine life.[1]

2.4 Introduction and Spread of Alien Species

Marine debris can serve as a vector for numerous species. Hence, floating debris can potentially transport and introduce species to new environments (Barnes, 2002; Winston et al., 1997). Donohue et al. (2001) recorded 13 invertebrate and 10 vertebrate species living on or within a tangle of debris comprising mostly derelict fishing gear in the Northwestern Hawaiian Islands. Similarly, Barnes and Fraser (2003) documented 10 species from 5 different phyla on a single plastic packing band floating in the Southern Ocean. Although none of the species documented in these studies were non-native, the results nonetheless point to the potential for marine debris to serve as vectors for alien species.

To date, the establishment of an alien species via marine debris has yet to be documented (Lewis et al., 2005; Barnes, 2002; Barnes and Milner, 2005; Masó et al.,

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[1] (http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/abandoned-and-derelict-vessels.html).

2003). The absence of such evidence probably reflects the paucity of research rather than the unlikelihood of such events. However, examples of non-native species arriving in new habitat have been well documented. For example, a 180-ton concrete dock cast adrift from Misawa, Japan, by the March 2011 tsunami was carried across the Pacific where it washed ashore in Oregon in the United States in June 2012 carrying at least 90 Japanese species including 6 species of non-native algae, crustaceans, and molluscs known to be invasive species in other parts of the world (Lam et al., 2013; Portland State University 2012). Removal of the dock and its burden of non-native species cost 85,000 United States dollars (Barnea et al., 2014).

A recent study by Goldstein et al. (2013) hints at the possibility of marine debris contributing to habitat expansion for the sea skater *Halobates sericeus* (of the *Hemiptera* order). They showed that abundance of *H. sericeus* was related to the availability of floating marine debris, and that such debris was used by the sea skater to attach its egg masses. This suggests that, in principle, *H. sericeus* and similar species could spread across ocean basins with the aid of marine debris.

Because marine debris is subject to surface and deep-water currents, the geographic spread of alien species by such debris is not expected to be random. For instance, the North Pacific convergence zone, which tends to concentrate marine debris, regularly occurs around the north-western Hawaiian Islands. Thus, the islands are subject to unusually high loads of marine debris, and perhaps associated invasive species.

Marine debris can also support the growth and transport of microbes (e.g., cyanobacteria, fungi, algae) to new habitats (Masó et al., 2003; Thiel and Gutow, 2005a and b; Zettler et al., 2013). Masó et al. (2003) found dinoflagellates, including those responsible for harmful algal blooms, growing on plastic debris, and raised the possibility that the increase in harmful algal blooms may be facilitated by the increasing abundance of marine debris.

2.5 Socioeconomics Impacts

The socioeconomic impacts of marine debris are a difficult problem to quantify, because many pollution problems and biological and environmental effects have taken a long time to identify and quantify, partly because of the diverse sources (lack of awareness, inadequate waste management, etc.), and because data on volume/mass, occurrence and distribution are seldom recorded. Furthermore, the literature is sparse for economic analyses addressing elements of potential effects. The Kommunenes Internasjonale Miljøorganisasjon (KIMO) studies (Hall, 2000; Mouat et al., 2010) are the most thorough, but inconsistencies, missing data, and absence of detail have been noted. In such cases, verifiable data were used for point estimates using a Benefits Transfer Approach (Ofiara and Brown, 1999; Unsworth and Petersen, 1995).

2.6 *Impacts on Beach Communities, Beach Use, Coastal Tourism*

2.6.1 *Beach cleaning*

Several references in the literature cite anecdotal information related to costs of beach cleaning. NRC (1995) reports the 1993 cost of beach cleaning at Virginia Beach, VA, United States of America, was 43,646 euros per km/yr (60,724 United States dollars per km/yr) and for Atlantic City, NJ, United States, was 215,225 euros per km/yr (299,439 US dollars per km/yr) (2011 Euro values given in parentheses; for all the conversions see Appendix). OSPAR Commission (2009) reports this cost for 2004 for the coast of the United Kingdom at 14 million British pounds per year (19.7 million euros per yr), for the Skagerrak coast, Sweden at 5.1 million euros per year (1.87 million euros per yr) for 2006, and Naturvardsverket (2009) reports the cost of cleaning marine debris on five beaches and in two ports in Poland for 2009 at 570,000 euros per year (632,120 euros per yr). Lane et al., 2007, estimated it would cost 286 million dollars per year to remove debris from the wastewater stream in South Africa (311 million dollars per year, 224 million euros per year -2011 values). A recent study by the Natural Resources Defense Council (NRDC) reports beach cleaning costs and waterway debris removal for 43 communities from South San Francisco to San Diego, California, as 10,993,010 dollars spent (Stickel et al., 2013).

2.6.2 Damage to beach use

Studies in the United States examined damage to beach use from marine debris and medical waste (see Appendix). A major wash-up of marine debris on the shore in 1976 closed New York beaches and caused 15-25 million dollars in lost revenues (43-71 million euros, 59-99 million dollars, in 2011 values; Swanson et al., 1978). ERA (1979) found that clean beaches in an adjacent state suffered piggyback effects from the 1976 event; the public avoided going to an “open-clean” beach in an adjacent state (Seaside Heights, New Jersey, United States) as if it too had marine debris and was closed, an example of avoidance behaviour resulting in lost revenues (943,638 euros per year, 2011 values). Extensive pollution and medical waste wash-ups occurred in 1987-1988 on New Jersey and New York beaches, with losses estimated at of 201-749 million euros at 2011 values for marine debris and medical waste; an average of 475 million euros (Ofiara and Brown, 1989 and 1999; Kahn et al., 1989; Swanson et. al., 1991) in 2011 values.

2.6.3 *Losses to tourism*

Ofiara and Brown (1989, 1999) found that marine debris wash-ups in New Jersey, United States, decreased beach attendance by 8.9 per cent -18.7 per cent in 1987 and by 7.9 to 32.9 per cent in 1988 (Appendix). A study in South Africa found that a decrease in beach cleanliness could decrease tourism spending by up to 52 per cent (Balance et al., 2000). In Sweden, research found that marine debris on beaches reduced tourism by between one and five per cent (OSPAR, 2009). Hence, even a limited presence of marine debris can decrease coastal tourism by between one to five per cent, and severe events can decrease beach visits by 8.4 per cent to 25.8 per cent (averaged limits).

2.7 Impacts on Commercial Fishing

The Marine Pollution Monitoring Management Group (MPMMG, 2002) reported the cost of marine debris removal in the United Kingdom fisheries at 33 million euros, and Watson and Bryson (Macfayden, 2009) reported a cost for one trap fisherman in the Scottish Clyde fishery of 21,000 dollars in lost gear and 38,000 dollars in lost time. Without more information, it is hard to give these estimates their proper context. Studies for the Kommunenes Internasjonale Miljøorganisasjon (KIMO) have estimated average losses per vessel from marine debris as follows: cleaning marine debris from nets GBP 4,065 or Euro 12,007; contaminated catch GBP 1,686 or Euro 2,183, snagged nets GBP 3,392 or Euro 3,820; fouled propellers Euro 182 euros (Hall, 2000; Mouat et al., 2010 - Appendix; GBP at 1998 values, Euro at 2008 values).

A recent study that examined blue crab ghost fishing from lost/abandoned traps/pots found an average mortality rate of 18 crabs/trap/year were harvested in Virginia-Chesapeake Bay, United States waters (sampled in the winter) (Bilkovic et al. 2014), compared to earlier mortality rate estimates of 20 crabs/trap/year in Maryland-Chesapeake Bay waters (Giordano et al. 2011), and 26 crabs/trap/year in Gulf of Mexico waters (Guillory, 1993). An earlier study examined ghost fishing catch rates during the crabbing season of 50 crabs/trap/year (live catch rate-capture rate) in Virginia-Chesapeake Bay waters (Havens et al. 2006). Bilkovic et al. (2014) further estimated an overall loss of 900,000 crabs or 300,000 United States dollars for Virginia-Chesapeake Bay, United States waters.

Impacts of lesser magnitude are summarized in Table 1.

Table 1. Summary of impacts of lesser magnitude, point estimates

Ghost Fishing:			
Brown et al. (2005)	Cantabrian Sea, Spain	1.46% loss-landings	Monkfishery
NRC (2008)	Not Available	up to 5% EU landings	
Allsopp et al. (2006)	United States	$250mill/yr loss-landings	Lobster fishery
Macfayden et al. (2009)	Louisiana, United States	4-10mill. Crabs/yr lost	Blue Crab fishery
Hall (2000)	United Kingdom	Avg. Cost cleanup = £L2355/hbr	
Mouat et al. (2010)	United Kingdom	Avg. Cost cleanup = €8034/hbr-harbours, €9492/hbr-marinas; €8253.hbr-composite	
Hall (2000)	Shetland Is. Livestock crofts, United Kingdom	96% reported marine debris caught in fences, 36% reported animals entangled, 20% reported animals ill	
Mouat et al. (2010)	Shetland Is. Livestock crofts, United Kingdom	71% reported marine debris caught in fences, 42% reported animals entangled or ill	
Hall (2000)	United Kingdom	11% reported cleanup costs of €20,199/yr, rest €0	

Table 2. Summary - Projections (2011 values)

Beach Cleaning Costs (KIMO, 2000,2009)	United Kingdom	€14.301mill/yr - €14.487mill/yr (avg. €14.394mill/yr)
Damage to Beach Use (S-O),	New York, New Jersey, United States	All causes: €1,403mill - €5,236mill (avg. €3,319mill) MD, Medical Waste: €201mill - €749mill(avg. €475mill)
Commercial Fishing (KIMO, 2000,2009),	United Kingdom	€8.308mill/yr - €8.935mill/yr (avg. €8.6215mill/yr)
Aquaculture (KIMO, 2000,2009),	United Kingdom	€94,338/yr
Harbors, Marinas (KIMO, 2000,2009),	United Kingdom	€491,641 - €944,510/yr (avg. €718,076/yr)
Damages to Vessels (S-O),	New York Harbour, United States	€749mill
Coastal Agriculture (KIMO, 2000,2009),	United Kingdom	€486,270 - €614,461/yr (avg. €550,366/yr)

Note: KIMO (2000, 2009) = Hall (2000), Mouat et al. (2010), S-O = Swanson et al., 1991, Ofiara and Brown, 1999, NA: not available.

2.8 Impacts from Invasive Species

The literature pertaining to economic impacts of invasive species is silent regarding marine debris, but it does contain some evidence about the dimensions of the impacts from invasive species. The Swedish Naturvardsverket (2009) cites the collapse of the anchovy fishery in the Black Sea due to the introduction of the American comb jellyfish at an estimated 240 million euros per year. Holt (2009) examined control and eradication costs associated with the Carpet sea squirt in Holyhead Harbour, Wales, and estimated those costs at 525,000 pounds over a 10-yr period (2009-2019); the costs of inaction were estimated at 6.87 million pounds for the same 10-yr period.

3. Assessment of the status of marine litter

3.1 Floating Marine Debris

Floating marine debris in the water column has been documented in the open ocean and in coastal waters. Results for densities of floating marine debris in different regions of the world’s oceans are shown in Table 3. However, comparisons between studies or even systematic status and trend analyses are challenging because of differences in the collection and measurement methodology used.

Table 3 Densities of floating marine debris in different regions

Location	Method	Density	Reference
Coastal North Atlantic Ocean	0.333mm mesh net	3537 items/km^2, 286.8 kg/km^2	Carpenter and Smith, 1972
North Atlantic Ocean Caribbean	0.947mm mesh net	1.023 g/cm^3	Colton et al., 1974
Northwest Pacific	0.50mm mesh net	up to 37.6 items/km^2	Day et al., 1990
North Pacific central gyre	0.333mm mesh net	334,271 items/km^2, 5,114 g/km^2	Moore et al., 2001
Southern California's coastal waters	0.333mm mesh net	7.25 items/m^3, 0.02g/m^3	Moore et al., 2002
California Current	0.333mm mesh net	3.29 items/m^3, 0.003g/m^3	Lattin et al., 2004
North Pacific Ocean, Kuroshio Current	0.333mm mesh net	174,000 items/km^2, 3600 g/km^2	Yamashita and Tanimura, 2007
California Current	0.505mm mesh net	0.011-0.033 items/m^3 (Median)	Gilfillan et al., 2009
Caribbean Sea	0.335mm mesh net	1414 ± 112 items/km^2	Law et al., 2010
Gulf of Maine	0.335mm mesh net	1534 ± 200 items/km^2	Law et al., 2010
North Atlantic Subtropical Gyre (near 30°N).	0.335mm mesh net	20,328±2324 items/km^2	Law et al., 2010
Cape Cod, Massachusetts, United States to Caribbean Sea	0.335mm mesh net	0.80~1.24 g/ ml, 0.97~1.04 g/ml	Moret-Ferguson et al., 2010
North Atlantic Ocean	0.335mm mesh net	0.808-1.24 g/ml	Moret-Ferguson et al., 2010
Southeast Bering Sea and United States west coast	0.505mm mesh net	0.004-0.19 items/m^3, 0.014-0.209 mg/m^3	Doyle et al., 2011
Northeast Pacific Ocean	0.333mm mesh net	Summer 2009: 0.448 items/m^2 (Median)	Goldstein et al., 2013
	0.202mm mesh net	Fall 2010: 0.021 items/m^2 (Median)	
South Pacific subtropical gyre	0.333mm mesh net	Mean: 26,898 items/km^2, 70.96 g/km^2	Eriksen et al., 2013
Australia	0.333mm mesh net	4256.4-8966.3 items/km^2	Reisser et al., 2013
Bay of Calvi (Mediterranean-Corsica)	0.2 mm mesh net	6.2 particles/100 m^2	Collignon et al., 2014
South-East Pacific (Chile)	visual observations	40ºS and 50ºS : <1 items/km^2; nearshore waters: >20 items/km^2	Thiel et al., 2003
Ligurian Sea, north-western Mediterranean	visual observations	1997:15-25 items/km^2 2000: 3-1.5 items/km^2	Aliani et al., 2003
Floating marine debris in fjords, gulfs and channels of southern Chile	visual observations	1- 250 items/km^2	Hinojosa and Thiel, 2009
North East Pacific Ocean	visual observations	0-15,222 items/km^2	Titmus and Hyrenbach et al.,

			2011
Northeast Pacific Ocean	visual observations	0.0014-0.0032 items/m^2	Goldstein et al., 2013
Straits of Malacca	visual observations	578 ± 219 items/m^2	Ryan, 2013
Bay of Bengal	visual observations	8.8 ± 1.4 items/m^2	Ryan, 2013

Note: Ship-based trawling surveys and visual observations are used for small and large debris, respectively.

In coastal waters, the type, composition and density of floating debris vary greatly among locations. The spatial distribution is influenced by anthropogenic activities, hydrographic and geomorphological factors, prevailing winds, and entry point (Barnes et al., 2009; Derraik, 2002). Generally, the distribution and composition of marine debris floating at sea depends largely on near-shore circulation patterns (Aliani et al., 2003; Lattin et al., 2004; Ribic et al., 2010; Thiel et al., 2003). Prevailing winds also affect the pattern of debris abundance. Greater quantities of plastics were observed at downwind sites (Browne et al., 2010; Collignon et al., 2012). Collignon et al. (2014) observed that the density of floating debris was five times higher before a strong wind event than afterwards. This was explained by the wind stress increasing the mixing and vertical redistribution of the plastic particles in the upper layers of the water column. However, most land-based litter is carried by water currents through rivers and storm-water (Ryan et al., 2009). The density of the debris in the southern California, United States coast water, after the storm was seven times higher than prior to the storm (Moore et al., 2002). The weight of plastic increased by more than 200 times after a storm in Santa Monica Bay, California, United States (Lattin et al., 2004). Higher densities of debris in coastal waters are also associated with human population density (Lebreton et al., 2012; Thiel et al., 2003).

In the open ocean, spatial patterns of debris are influenced by the interaction of large-scale atmospheric and oceanic circulation patterns, leading to particularly high accumulations of floating debris in the subtropical gyres (Howell et al., 2012; Goldstein et al., 2013; Martinez et al., 2009). A high profile publication in the *Science* journal presented over 20 years of data clearly demonstrating that some of the most substantial accumulations of debris are now in oceanic gyres far from land (Law et al., 2010). The models developed by Martinez et al. (2009) suggest that marine debris deposited in coastal zones tends to accumulate in the central oceanic gyres within two years after deposition. The persistent floating debris will accumulate in mid-ocean sub-tropical gyres, forming so-called garbage patches (Kaiser, 2010; Lebreton et al., 2012) (See Figure 1).

Although the type of litter found in the world's oceans is highly diverse, plastics are by far the most abundant material recorded. Plastic debris was first reported in the oceans in the early 1970s (Carpenter and Smith, 1972; Colton et al., 1974). Plastics are estimated to represent between 60 per cent and 80 per cent of the total marine debris (Derraik, 2002; Gregory and Ryan, 1997). Almost all aspects of daily life involve plastics, and consequently the production of plastics has increased substantially in the last 60 years and this trend continues. The fragmentation of plastics generates microplastics. For example, in sampling the South Pacific subtropical gyre, 1.0mm - 4.7mm particles accounted for 55 per cent of the total count and 72 per cent of the total weight (Eriksen et al., 2013). Research on the amount, distribution, composition and potential impact of microparticles has received increasing attention.

Plastic debris continues to accumulate in the marine environment. Goldstein et al. (2013) show that the density of microplastics within the North Pacific Central Gyre has increased by two orders of magnitude in the past four decades. In contrast, there is no significant trend in the density of surface water plastics in the North Atlantic from 1986 to 2008, despite increases in plastic production during this time (Law et al., 2010). Some form of loss must be taking place to offset the presumed increase in input of plastics to the ocean. Possible sinks for floating plastic debris include fragmentation, sedimentation, shore deposition, and ingestion by marine organisms (Law et al., 2011).

3.2 Beach debris

Millions of volunteers in more than 150 countries are involved in beach-cleanup activities on International Coastal Cleanup Day every year (Ocean Conservancy, 2011). The volunteers' participation contributes to extensive sampling and helps to obtain more information from a wider range of sites (Rees and Pond, 1995). The density of debris reported from the beaches in different regions of the world is listed in Table 4. For most of the beaches, the major debris is plastic. The spatial distribution of plastic debris is affected by multiple factors, including land uses, human population, fishing activity, and oceanic current systems (Ribic et al., 2010).

Table 4. Density of beach debris in different beaches

Location	Density	Reference
Dominica	1.9-6.2 items/m, 51.5-153.7 g/m	Corbin and Singh, 1993
St. Lucia	4.5-11.2 items/m, 8.2-109.2 g/m	Corbin and Singh, 1993
Panama	3.6 items/m^2 (180/50 m^2)	Garrity and Levings, 1993
Persian Gulf, United Arab Emirates	0.84 items/ m^2	Khordagui and Abu-Hilal, 1994
Tasmania, Australia	300 items/km, 0.09-0.35 items/m	Jones, 1995
Marmion Marine Park, Australia	2.74 items/m, 0.54 g/m	Jones, 1995
West Australia, Marmion Marine Park, Australia	3.66 items/m, 0.12 g/m	Jones, 1995
Northern New South Wales, Australia	10.9 items/km^2	Frost and Cullen, 1997

Transkei Coast, South Africa	19.6-72.5 items/m, 42.8-164.1 g/m	Madzena and Lasiak, 1997
Bird Island, South Georgia	0.014-0.21 items/m	Walker et al., 1997
New Jersey, United States	0.36-6.4 items/m	Ribic, 1998
Cliffwood Beach,New Jersey, United States	2.7-3.7 items/m^2	Thornton and Jackson, 1998
Caribbean Sea: Curaçao	60 items/m, 4.5 kg/m	Debrot et al., 1999
Orange County, California, United States	1709 items/m	Moore et al., 2001
Ensenada, Baja California, Mexico	1.525 items/m^2 (including natural litter)	Silva-Iñiguez and Fischer, 2003
Japanese beaches	2144 g/100 m^2, 341 items/100 m^2	Kusui and Noda, 2003
Russian beaches	1344 g/100 m^2, 20.7 items/100 m^2	Kusui and Noda, 2003
Volunteer Beach, Playa Voluntario, Falkland Islands (Malvinas)	accumulation rate:77±25 items/km/month	Otley and Ingham, 2003
Gulf of Aqaba, Red Sea	1.64-7.38 items/m	Abu-Hilal and Al-Najjar, 2004
Gulf of Oman, Oman	1.79 items/m; 27.02g/m	Claerboudt , 2004
Anxious Bay, Australia	1.9-15.0 kg/km	Edyvane et al. 2004
Point Pleasant Park, Halifax Harbour, Canada	accumulation rate: 355±68 items/month	Walker et al., 2006
Rio de Janeiro, Brazil	13.76 items /100 m^2	Oigman-Pszczol and Creed, 2007
NOWPAP region	570 items/100 m^2, 3864 g/100 m^2	UNEP/NOWPAP, 2008
Gulf of Aqaba, Red Sea	2.8 items/m^2, 0.31 kg/m^2	Abu-Hilal and Al-Najjar, 2009
Chile	1.8 items/m^2	Bravo et al., 2009
OSPAR region	712 items/100m	OSPAR Commission, 2009
Belgium	6429 ± 6767 items/100m	Van Cauwenberghe et al., 2013
Caribbean Sea, Bonaire	115 ± 58 items/m, 3408 ± 1704 g/m (GM)	Debrot, et al., 2013
Chile	27 items/m^2 (small plastic)	Hidalgo-Ruz and Thiel, 2013
Mumbai, India	68.83 items/m^2, 7.49 g/m^2 (Plastic debris)	Jayasiri et al., 2013
Nakdong River Estuary, Republic of Korea	large plastics: 8205(M), 27,606 items/m^2(S) ; mesoplastics:238 (M), 237 particles/m^2(S) macroplastics : 0.97(M), 1.03 particles/m^2(S)	Lee et al., 2013
Monterey Bay, CA, United States	0.03-17.1 items/m^2 1±2.1 items/m^2	Rosevelt et al., 2013
Turkish Western Black Sea coast	0.085-5.058 items/m^2	Topçu et al., 2013

20 beaches, Republic of Korea	480.9 (±267.7) count · 100 m^{-1} for number, 86.5 (±78.6) kg · 100 m^{-1} for weight, 0.48 (±0.38) m^3 · 100 m^{-1} for volume	Hong et al., 2013

GM: geometric mean; M: surveying results in May; S: surveying results in September.

Beach debris density may be linked to the number of tourists and the cleaning frequency (Bravo et al., 2009; Kuo and Huang, 2014). For example, beach debris densities in central Chile were lower than in northern and southern Chile, which could be due to different attitudes of beach users or intensive beach cleaning in central regions (Bravo et al., 2009). Rodriguez-Santos et al. (2005) found that the quantity of litter depends on beach visitor density. Ocean current patterns, sand types, wave action, and wind exposure have further effects on litter abundance. For example, in Monterey Bay, California, United States, the seasonal variability in debris abundance may be a function of oceanic winds, as well as the possibility that seasonal current patterns may drive debris deposition (Rosevelt et al., 2013).

Although marine debris density is usually associated with population density, a few studies contradict this. Ribic et al. (2010) show no trends over several decades in beach-debris densities along the Eastern Atlantic seaboard of the United States, although large percentage increases in coastal population occurred in the south-east Atlantic region and a smaller percentage increase in coastal population occurred in the north-east region.

3.3 Benthic marine debris

The occurrence of litter on the seafloor has been far less investigated than in surface waters or on beaches, principally because of the high cost and the technical difficulties involved in sampling the seafloor. Nevertheless, a few investigations of benthic debris have been recorded, including on the continental shelves, on raised seabed features, such as seamounts, ridges and banks, in canyons and in polar regions. The surveying methods for the density and composition of benthic marine debris include bottom trawling, coring, scuba diving, the use of submersibles, snorkelling, manta tows and sonar (Spengler and Costa, 2008) and more recently, towed camera systems and remotely operated vehicles (ROVs).

Abundances of benthic debris range from dozens to more than hundreds of thousands items per square kilometre. As more areas of Europe's seafloor are being explored, benthic litter is progressively being revealed to be more widespread than previously assumed. Pham et al. (2014) reported data on litter distribution and density collected during 588 video and trawl surveys across 32 sites in European waters (35-4500 m depth). Debris was found to be present in the deepest areas and at locations as remote from land as the Charlie-Gibbs Fracture Zone across the Mid-Atlantic Ridge. The highest litter density occurred in submarine canyons, reaching an average (± SE) of 9.3±2.9 items ha^{-1}. The lowest density was found on continental shelves and on ocean ridges; mean (± SE) litter density of 2.2±0.8 and 3.9±1.3 items ha^{-1}, respectively. As for most other marine environments studied, plastic was the most prevalent litter item found on the seafloor. Woodall et al (2015) showed the litter was ubiquitous on deep-sea raised benthic features, such as seamounts, banks and ridges, A total of 56 items was found in the Atlantic Ocean over a survey area of 11.6 ha, and 31 items in the Indian Ocean over 5.6 ha, with a significant difference in the type of litter between areas sampled in the Indian Ocean (where the dominant litter type was fishing gear) and sites in the Atlantic Ocean (which had mixed refuse).

Litter from fishing activities (derelict fishing lines and nets) was particularly common on seamounts, banks, mounds and ocean ridges. A significant source of benthic debris is lost and discarded fishing gear, which is of particular concern due to ghost fishing effects that can kill both commercial and non-commercial species. Laist (1996) reports annual gear loss rates of about one percent for gillnet fisheries and between 5 - 30 percent for trap fisheries in United States fisheries. Whereas trap loss rates in the American lobster fishery are relatively low (5-10 percent), because the fishery involves more than 3 million deployed traps, the lobster fishery alone may account for the loss of more than 150,000 traps per year.

Hydrography, geomorphology, and anthropogenic activities all affect the abundance, type, and location of debris reaching the seafloor (Barnes et al., 2009; Galgani et al., 2000; Schlining et al., 2013). Because they facilitate the transport and deposition of debris, submarine canyons act as conduits for debris, transporting it from the coast to the deep sea (Ramirez-Llodra et al., 2013; Schlining et al., 2013). Ramirez-Llodra et al. (2013) suggest that debris in a canyon mainly originates from coastal areas, that plastic debris can be transported easily by canyon-enhanced currents, whereas heavy debris is usually discarded from ships. Wei et al. (2012) indicate that the debris density was higher in the eastern than that in the western Gulf of Mexico, primarily because of shipping lanes, offshore oil- and gas-installation platforms, as well as fishing activities. The litter density and diversity were independent of depth of water and of distance from land. Galgani et al. (2000) report that only small amounts of debris were collected on the continental shelf, mostly in canyons descending from the continental slope. Ramirez-Llodra et al. (2013) report accumulation of litter with increasing depth, but the mean weight at different depths, or between the open slope and canyons, showed no significant variation. Schlining et al. (2013) found debris clustered just below the edge of canyon walls or on the outside of canyon meanders. Wei et al. (2012) indicated that the total density of anthropogenic waste was significantly different between parallel depth transects. Woodall et al (2015) concluded that the pattern of accumulation and composition of the litter was determined by a complex range of factors both environmental and anthropogenic.

Table 5. Density of benthic debris in different regions

Location	Method	Density	Depth range	Reference
Bay of Biscay, France	trawl	0.263-4.94 items/ha	0-100m	Galgani et al., 1995a
Northwestern Mediterranean	trawl	19.35 items/ha	750m	Galgani et al., 1995b
French Mediterranean coast	trawl	0-78 items/ha	100-1600m	Galgani et al., 1996
European coast	trawl	0-1010 items /ha	<2200m	Galgani et al., 2000
Eastern China Sea and the south coast of the Republic of Korea	trawl	30.6-109.8 kg/km^2	—	Lee et al., 2006
Greek Gulfs	trawl	72-437 items/km^2, 7-47.4 kg/km^2	—	Koutsodendris et al., 2008
Gulf of Aqaba, Red Sea	SCUBA	2.8 items/m^2; 0.31 kg/m^2	—	Abu-Hilal et al., 2009
submarine canyons and the continental shelf off California, United States	submersible	1.7 items/100m	20-365 m	Watters et al., 2010
West coast of the United States	trawl	67.1 items/km^2	55-1280m	Keller et al., 2010
West coast of Portugal	ROV	1100 items/km^2	850-7400 m	Mordecai et al., 2011
Eastern Fram Strait west of Svalbard	Image observation	3635-7710 items/km^2	2500m	Bergmann et al., 2012
Gulf of Mexico	trawl	<28.4 items/ha	359-3724m	Wei et al., 2012
Antalya Bay, Eastern Mediterranean	trawl	18.5-2,186 kg/km^2, 115-2,762 items/km^2	200-800m	Güven et al., 2013
Belgium	trawl	3125 ± 2830 items/km^2	—	Van Cauwenberghe et al., 2013
Mediterranean Sea	trawl	0.02-3264.6 kg/km^2	900-2700m	Ramirez-Llodra et al., 2013
Monterey Bay, California, United States	ROV	---	25-3971m	Schlining et al., 2013
Atlantic Ocean, Mediterranean Sea and Indian Ocean	Core (microplastic)	1.4-40 pieces/50ml sediment 13.4±3.5 pieces/50ml sediment;	1000-3500m	Woodall et al,. 2014
Atlantic Ocean	ROV	12.23-0.59 items/ha	200-2800m	Woodall et al,. 2015
Indian Ocean	ROV	17.39-0.75 items/ha	1320-1610m	Woodall et al,. 2015

ROV: Remotely Operated Vehicle; SCUBA: Self-Contained Underwater Breathing Apparatus

Debris continuously accumulates on the deep seabed; some research shows a significant increasing trend. Watters et al. (2010) reported a significant increase in the amount of litter at some of shelf locations off California, United States, between 1993 and 2007. The debris density has continued increasing, and has doubled during the last decade in the Arctic deep sea (Bergmann and Klages, 2012). The density of microplastics in sediments has been increasing along the Belgian coast (Claessens et al., 2011). However, some studies did not observe significant temporal increases, for example, in litter abundance between 1989 and 2010 in Monterey Canyon, central California, United States (Schlining et al., 2013).

4. Prevention and Clean-up of Marine Debris

Numerous policies, global, international, national and local, address various aspects of marine debris. Some countries have banned outright the use of certain plastic derivative products.

5. Gaps, Needs, Priorities

Marine debris is a complex cultural and multi-sectoral problem that imposes tremendous ecological, economic, and social costs around the world. One of the substantial barriers to addressing marine debris is the absence of adequate scientific research, assessment, and monitoring. There is a gap in scientific research to better understand the sources, fates, and impacts of marine debris (NOAA and EPA, 2011; NRC, 2008). Scalable, statistically rigorous and, where possible, standardized monitoring protocols are needed to monitor changes in conditions as a result of efforts to prevent and reduce the impacts of marine debris. Although monitoring of marine debris is currently carried out within several countries around the world (often on the basis of voluntary efforts by non-governmental organizations), the protocols used tend to be very different, preventing comparisons and harmonization of data across regions or timescales (NOAA and EPA, 2011; Cheshire et al., 2009).

There is a gap in information needed to evaluate impacts of marine debris on coastal and marine species, habitats, economic health, human health and safety, and social values. More information is also needed to understand the status and trends in amounts, distribution and types of marine debris. There is also a gap in capacity in the form of new technologies and methods to detect and remove accumulations of marine debris (NOAA and EPA, 2011), as well as in means of bringing home to the public in all countries the significance of marine debris and the important part that the public can play in combating it.

Besides, the ways in which waste management is conducted are often a barrier. This is a global problem, but waste is managed on a very local level. Truly biodegradable, naturally occurring, biopolymers are becoming more wide spread and commercially available. There is a need to pursue truly biodegradable biopolymer alternatives to plastic (Chanprateep, 2010).

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