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

The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

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,

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 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

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 sorbed 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 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 behavior 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.,

[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 deeper 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 Naturvardsverk (2009) reports the cost of

2.7 Impacts on Commercial Fishing

The Marine Pollution Monitoring Management Group (MPMMG, 2002) reported the

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 - OS,	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 - OS,	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), **OS** = 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		

			2011
Northeast Pacific Ocean	visual observations	0.0014-0.0032 [illegible]	

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

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,		

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

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

Table5. 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	72(2] 4 3 72(b 6 (i) 2 2 1 5 . 8 (o) 1 9 . 2 (( )] T J . 2 4 6 3 2) 1 7 . 4 (k) 0 . h (			

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