Chapter 2
Global Distribution, Composition and Abundance of Marine Litter

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Abstract Marine debris is commonly observed everywhere in the oceans. Litter enters the seas from both land-based sources, from ships and other installations at sea, from point and diffuse sources, and can travel long distances before being stranded. Plastics typically constitute the most important part of marine litter sometimes accounting for up to 100 % of floating litter. On beaches, most studies have demonstrated densities in the 1 item m^{-2} range except for very high concentrations because of local conditions, after typhoons or flooding events. Floating marine debris ranges from 0 to beyond 600 items km^{-2}. On the sea bed, the abundance of plastic debris is very dependent on location, with densities ranging from 0 to >7700 items km^{-2}, mainly in coastal areas. Recent studies have demonstrated that pollution of microplastics, particles <5 mm, has spread at the surface of oceans, in the water column and in sediments, even in the deep sea. Concentrations at the water surface ranged from thousands to hundred thousands of particles km^{-2}. Fluxes vary widely with factors such as proximity of urban activities, shore and coastal uses, wind and ocean currents. These enable the presence of accumulation areas in oceanic convergence zones and on the seafloor, notably in coastal canyons. Temporal trends are not clear with evidences for increases, decreases or without changes, depending on locations and environmental conditions. In terms of distribution and quantities, proper global estimations based on standardized approaches are still needed before considering efficient management and reduction measures.

Keywords Marine litter · Plastic · Distribution · Beaches · Seafloor · Microplastics · Floating litter

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2.1 Introduction

Anthropogenic litter on the sea surface, beaches and seafloor has significantly increased over recent decades. Initially described in the marine environment in the 1960s, marine litter is nowadays commonly observed across all oceans (Ryan 2015). Together with its breakdown products, meso-particles (5–2.5 cm) and micro-particles (<5 mm), they have become more numerous and floating litter items can be transported over long distances by prevailing winds and currents (Barnes et al. 2009).

Humans generate considerable amounts of waste and global quantities are continuously increasing, although waste production varies between countries. Plastic, the main component of litter, has become ubiquitous and forms sometimes up to 95 % of the waste that accumulates on shorelines, the sea surface and the seafloor. Plastic bags, fishing equipment, food and beverage containers are the most common items and constitute more than 80 % of litter stranded on beaches (Topçu et al. 2013; Thiel et al. 2013). A large part of these materials decomposes only slowly or not at all. This phenomenon can also be observed on the seafloor where 90 % of litter caught in benthic trawls is plastic (Galil et al. 1995; Galgani et al. 1995, 2000; Ramirez-Llodra et al. 2013).

Even with standardized monitoring approaches, the abundance and distribution of anthropogenic litter show considerable spatial variability. Strandline surveys and cleanings as well as regular surveys at sea are now starting to be organized in many countries in order to generate information about temporal and spatial distribution of marine litter (Hidalgo-Ruz and Thiel 2015). Accumulation rates vary widely and are influenced by many factors such as the presence of large cities, shore use, hydrodynamics and maritime activities. As a general pattern, accumulation rates appear to be lower in the southern than in the northern hemisphere. Enclosed seas such as the Mediterranean or Black Sea may harbor some of the highest densities of marine litter on the seafloor, reaching more than 100,000 items km^{-2} (Galgani et al. 2000). In surface waters, the problem of plastic fragments has increased in the last few decades. From the first reports in 1972 (Wong et al. 1974), the quantities of microparticles in European seas have grown in comparison to data from 2000 (Thompson et al. 2004). Recent data suggest that quantities of microparticles appear to have stabilized in the North Atlantic Ocean over the last decade (Law et al. 2010). Little is known about trends in accumulation of debris in the deep sea. Debris densities on the deep seafloor decreased in some areas, such as in the Bay of Tokyo from 1996 to 2003 and in the Gulf of Lion between 1994 and 2009 (Kuriyama et al. 2003; Galgani et al. 2011a, b). By contrast, in some areas around Greece, the abundance of debris in deep waters has substantially increased over a period of eight years (Stefatos et al. 1999; Koutsodendris et al. 2008) and on the deep Arctic seafloor of the HAUSGARTEN observatory over aperiod of ten years (Bergmann and Klages 2012). Interpretation of temporal trends is complicated by seasonal changes in the flow rate of rivers, currents, wave action, winds etc. Decreasing trends of macroplastics (>2.5 cm) on beaches

of remote islands suggest that regulations to reduce dumping at sea have been successful to some extent (Eriksson et al. 2013). However, both the demand and the production of plastics reached 299 million tons in 2013 and are continuing to increase (PlasticsEurope 2015).

2.2 Composition

Analysis of the composition of marine litter is important as it provides vital information on individual litter items, which, in most cases, can be traced back to their sources. Sources of litter can be characterised in several ways (see also Browne 2015). One common method is to classify marine litter sources as either land-based or ocean-based, depending on where the litter entered the sea. Some items can be attributed with a high level of confidence to certain sources such as fishing gear, sewage-related debris and tourist litter. So-called use-categories provide valuable information for developing reduction measures (Galgani et al. 2011a).

Land-based sources include mainly recreational use of the coast, general public litter, industry, harbors and unprotected landfills and dumps located near the coast, but also sewage overflows, introduction by accidental loss and extreme events. Marine litter can be transported to the sea by rivers (Rech et al. 2014; Sadri and Thompson 2014) and other industrial discharges and run-offs or can even be blown into the marine environment by winds. Ocean-based sources of marine litter include commercial shipping, ferries and liners, both commercial and recreational fishing vessels, military and research fleets, pleasure boats and offshore installations such as platforms, rigs and aquaculture sites. Factors such as ocean current patterns, climate and tides, the proximity to urban, industrial and recreational areas, shipping lanes and fishing grounds also influence the types and amount of litter that are found in the open ocean or along beaches.

Assessments of the composition of litter in different marine regions show that "plastics", which include all petroleum-based synthetic materials, make up the largest proportion of overall litter pollution (e.g. Pham et al. 2014). Packaging, fishing nets and pieces thereof, as well as small pieces of unidentifiable plastic or polystyrene account for the majority of the litter items recorded in this category (Galgani et al. 2013). Some of this can take hundreds of years to break down or may never truly degrade (Barnes et al. 2009).

Whether or not visual observations from ships and airplanes, observations using underwater vehicles, manned or not, acoustics and finally trawling will provide the necessary detail to characterise litter and eventually define sources is not always clear. Previous notions that at a global scale most of the marine litter is from land-based sources rather than from ships, were confirmed (Galgani et al. 2011b). Marine litter found on beaches consists primarily of plastics (bottles, bags, caps/lids, etc.), aluminium (cans, pull tabs) and glass (bottles) and mainly originates from shoreline recreational activities but is also transported by the sea by currents. In some cases, specific activities account for local litter densities well

above the global average (Pham et al. 2014). For example, marine litter densities on beaches can be increased by up to 40 % in summer because of high tourist numbers (Galgani et al. 2013). In some tourist areas, more than 75 % of the annual waste is generated in summer, when tourists produce on average 10–15 % more waste than the inhabitants; although not all of this waste enters the marine environment (Galgani et al. 2011b).

In some areas such as the North Sea or the Baltic Sea, the large diversity of items and the composition of the litter recorded indicate that shipping, fisheries and offshore installations are the main sources of litter found on beaches (Fleet et al. 2009). In some cases, litter can clearly be attributed to shipping, sometimes accounting for up to 95 % of all litter items in a given region, a large proportion of which originates from fishing activities often coming in the form of derelict nets (Van Franeker et al. 2011). In the North Sea, this percentage has been temporally stable (Galgani et al. 2011a) but litter may be supplemented by coastal recreational activities and riverine input (Lechner et al. 2014; Morritt et al. 2014). Studies along the US west coast, specifically off the coast of the southern California Bight (Moore and Allen 2000; Watters et al. 2010; Keller et al. 2010; Schlining et al. 2013) have shown that ocean-based sources are the major contributors to marine debris in the eastern North Pacific with, for example, fishing gear being the most abundant debris off Oregon (June 1990). Investigations in coastal waters and beaches around the northern South China Sea in 2009 and 2010 indicated that plastics (45 %) and Styrofoam (23 %) accounted for more than 90 % of floating debris and 95 % of beached debris. The sources were primarily land-based and mostly attributed to coastal recreational activities (Lee et al. 2013). In the Mediterranean, reports from Greece classify land-based (69 % of the litter) and vessel-based (26 %) waste as the two predominant sources of litter (Koutsodendris et al. 2008).

2.3 Distribution

2.3.1 Beaches

Marine debris is commonly found at the sea surface or washed up on shorelines, and much of the work on marine litter has focussed on coastal areas because of the presence of sources, ease of access/assessment and for aesthetic reasons (McGranahan et al. 2007). Marine litter stranded on beaches is found along all coasts and has become a permanent reason for concern. Beach-litter data are derived from various approaches based on measurements of quantities or fluxes, considering various litter categories, and sampling on transects of variable width and length parallel or perpendicular to the shore. This makes it difficult to draw a quantitative global picture of beach litter distribution. In general, methods that are used for estimating amounts of marine debris on beaches are considered cheap and fairly reliable, but it is not clear how it relates to litter at sea, floating or not. Moreover, in some coastal habitats, litter may be of terrestrial origin and

may never actually enter the sea. Most surveys are done with a focus on cleaning, thereby missing proper classification of litter items. When studies are not dedicated to specific items, litter is categorized by the type of material, function or both. Studies record the numbers, some the mass of litter and some do both (Galgani et al. 2013). Evaluations of beach litter reflect the long-term balance between inputs, land-based sources or stranding, and outputs from export, burial, degradation and cleanups. Then, measures of stocks may reflect the presence and amounts of debris. Factors influencing densities such as cleanups, storm events, rain fall, tides, hydrological changes may alter counts, evaluations of fluxes and, even if surveys can track changes in the composition of beach litter, they may not be sensitive enough to monitor changes in the abundance (Ryan et al. 2009). This problem can be circumvented by recording the rate, at which litter accumulates on beaches through regular surveys that are performed weekly, monthly or annually after an initial cleanup (Ryan et al. 2009). This is actually the most common approach, revealing long-term patterns and cycles in accumulation, requiring nonetheless much effort to do surveys. However, past studies may have vastly underestimated the quantity of available debris because sampling was too infrequent (Smith and Markic 2013).

It is unfeasible to review the hundreds of papers on beach macro-debris, which often apply different approaches and lack sufficient detail (see also Hidalgo-Ruz and Thiel 2015). Most studies range from a local (Lee et al. 2013) to a regional scale (Bravo et al. 2009) and cover a broad temporal range. Information on sources, composition, amounts, usages, baseline data and environmental significance are often also gathered (Cordeiro and Costa 2010; Debrot et al. 2013; Rosevelt et al. 2013) as such data are easier collected. Most studies record all litter items encountered between the sea and the highest strandline on the upper shore. Sites are often chosen because of their ecological relevance, accessibility and particular anthropogenic activities and sources. Factors influencing the accumulation of debris in coastal areas include the shape of the beach, location and the nature of debris (Turra et al. 2014). In addition, most sediment-surface counts do not take buried litter into account and clearly underestimate abundance, which biases composition studies. However, raking of beach sediments for litter may disturb the resident fauna. Apparently, a good correlation exists between accumulated litter and the amount arriving, indicating regular inputs and processes. Recent experiments with drift models in Japan indicate good correlation of flux with litter abundances on beaches (Yoon et al. 2010; Kataoka et al. 2013).

It appears that glass and hard plastics are accumulating more easily on rocky shores (Moore et al. 2001a). Litter often strands on beaches that lack strong prevalent winds, which may blow them offshore (Galgani et al. 2000; Costa et al. 2011). Abundance or composition of litter often varies even among different parts of an individual beach (Claereboudt 2004) with higher amounts found frequently at high-tide or storm-level lines (Oigman-Pszczol and Creed 2007). Because of this and beach topography, patchiness is a common distribution pattern on beaches, especially for smaller and lighter items that are more easily dispersed or buried (Debrot et al. 1999).

It is very difficult to compare litter concentrations of various coastal areas (with different population densities, hydrographic and geological conditions) obtained from various studies with different methodologies, especially when the sizes of debris items that are taken into account are also different. Nevertheless, common patterns indicate the prevalence of plastics, greater loads close to urban areas and touristic regions (Barnes et al. 2009). Data expressed as items m^{-2} or larger areas are more convenient for comparisons. Most studies have reported densities in the m^{-2} range (Table 2.1). High concentrations of up to 37,000 items per 50-m beach line (78.3 items m^{-2}) were recorded in Bootless Bay, Papua New Guinea (Smith 2012) because of specific local conditions, following typhoons (3,227 items m^{-2}; Liu et al. 2013) or flooding events (5,058 items m^{-2}; Topçu et al. 2013). Data expressed as quantities per linear distance are more difficult to compare because the results depend on beach size/width. Plastic accounts for a large part of litter on beaches from many areas with up to 68 % in California (Rosevelt et al. 2013), 77 % in the south east of Taiwan (Liu et al. 2013),

Table 2.1 Comparison of mean litter densities from recent data worldwide (non-exhaustive list)

Region	Density (m^{-2})	Density (linear m^{-1})	Plastic (%)	References
SW Black Sea	0.88 (0.008–5.06)	24 (1.7–197)	91	Topçu et al. (2013)
Costa do Dende, Brazil	n.d.	9.1	75	Santos et al. (2009)
Cassina, Brazil	n.d.	5.3–10.7	48	Tourinho and Fillmann (2011)
Gulf of Aqaba	2 (1–6)	n.d.	n.d.	Al-Najjar and Al-Shiyabet (2011)
Monterey, USA	1 ± 2.1	n.d.	68	Rosevelt et al. (2013)
North Atlantic, USA	n.d.	0.10 (0.2)	n.d.	Ribic et al. (2010)
North Atlantic, USA	n.d.	0.42 (0.1)	n.d.	Ribic et al. (2010)
North Atlantic, USA	n.d.	0.08 (0.2)	n.d.	Ribic et al. (2010)
South Caribbean, Bonaire	1.4 (max. 115)	n.d.	n.d.	Debrot et al. (2013)
Bootless Bay, Papua New Guinea	15.3 (1.2–78.3)	n.d.	89	Smith (2012)
Nakdong, South Korea	0.97–1.03	n.d.	n.d.	Lee et al. (2013)
Kaosiung, Taiwan	0.9 (max. 3,227)	n.d.	77	Liu et al. (2013)
Tasmania	0.016–2.03	n.d.	n.d.	Slavin et al. (2012)
Midway, North Pacific	n.d.	0.60–3.52	91	Ribic et al. (2012a)
Chile	n.d.	0.01–0.25	n.d.	Thiel et al. (2013)
Heard Island, Antarctica	n.d.	0–0.132	n.d.	Eriksson et al. (2013)

Ranges of values are given in parentheses

86 % in Chile (Thiel et al. 2013), and 91 % in the southern Black Sea (Topçu et al. 2013). However, other types of litter or specific types of plastic may also be important in some areas, in terms of type (Styrofoam, crafted wood) or use (fishing gear).

For trends in the amount of litter washed ashore and/or deposited on coastlines, beach litter monitoring schemes provide the most comprehensive data on individual litter items. Large data sets have already been held by institutions (Ribic et al. 2010) or NGO's such as the Ocean Conservancy through their International Coastal Cleanup scheme for 25 years, or the EU OSPAR marine litter monitoring program, which started over 10 years ago and covers 78 beaches (Schultz et al. 2013). The lack of large-scale trends in the OSPAR-regions is probably due to small-scale heterogeneity of near-shore currents, which evoke small-scale heterogeneity in deposition patterns on beaches (Schulz et al. 2013).

Ribic et al. (2010, 2012b) derived several nonlinear models to describe the development of pollution of coastal areas with marine litter. There were long-term changes in indicator debris on the Pacific Coast of the U.S. and Hawaii over the nine-year period of the study. Ocean-based indicator debris loads declined substantially while at the same time land-based indicator items had also declined, except for the North Pacific coast region where no change was observed. Variation in debris loads was associated with land- and ocean-based processes with higher land-based debris loads being related to larger local populations. Overall and at the local scale, drivers included fishing activities and oceanic current systems for ocean-based debris and human population density and land use status for land-based debris.

At local scales, concentrations of specific items may be largely driven by specific activities or new sources. For example, 41 % of the total debris from beaches in California was of Styrofoam origin, with no other explanation than an increased use of packaging, which degrades very easily (Ribic et al. 2012b). Small-sized items may form an important fraction of debris on beaches. For example, up to 75 % of total debris from the southern Black Sea was smaller than 10 cm (Topçu et al. 2013). Small-sized particles include fragments smaller than 2.5 cm (Galgani et al. 2011b), the so-called meso-particles or mesodebris, which is, unlike macrodebris, often buried and not always targeted by cleanups. Stranding fluxes are then difficult to evaluate and a decrease in the amount of litter at sea will only slow the rate of stranding. Little attention has been paid to sampling design and statistical power even though optimal sampling strategies have been proposed (Ryan et al. 2009). Densities of small-sized debris were found to be very high in some areas where, in addition to floating debris, they can pose a direct threat to wildlife, especially to birds that are known to ingest plastic (Kühn et al. 2015; Lusher 2015).

2.3.2 Floating Marine Debris

Floating debris constitutes the fraction of debris in the marine environment, which is transported by wind and currents at the sea surface, and is thus directly related to the pathways of litter at sea. Floating litter items can be transported by the

currents until they sink to the seafloor, be deposited on the shore or degrade over time (Andrady 2015). While the occurrence of anthropogenic litter items floating in the world oceans was reported already decades ago (Venrick et al. 1972; Morris 1980), the existence of accumulation zones of Floating Marine Debris (FMD) in oceanic gyres has only recently gained worldwide attention (Moore et al. 2001b).

Synthetic polymers constitute the major part of floating marine debris, the fate of which depends on their physico-chemical properties and the environmental conditions. As high-production volume polymers such as polyethylene and polypropylene have lower densities than seawater, they float until they are washed ashore or sink because their density changes due to biofouling and leaching of additives. While being subject to biological, photic or chemical degradation processes, they can be physically degraded gradually into smaller fragments until becoming microplastics, which is often defined as the size fraction <5 mm. This fraction requires different monitoring techniques, such as surface net trawls, and is therefore treated elsewhere (Löder and Gerdts 2015; Lusher 2015). Floating macrolitter is typically monitored by visual observation from ships, though results from net trawls are also being reported. The spatial coverage and thus the representativeness of the quantification depends on the methodology applied. Also, observation conditions, such as sea state, elevation of the observation position and ship speed affect results.

Existing datasets indicate substantial spatial variability and persistent gradients in floating marine litter concentrations (e.g. Erikssen et al. 2014). The variations can be attributed to differential release pathways or specific litter accumulation areas. Because of inconsistent reporting schemes used in scientific publications, data sets are often not comparable. Typically, item numbers are reported per surface area. Mass-based concentrations can then only be derived through estimates. Differences are found between studies in size ranges, concentration units and item categories used. As the number of pieces increases drastically with decreasing size of the observed litter items, the reporting of corresponding size classes is of high importance for comparing debris abundances among studies. Apart from the difficulty in reporting sizes correctly from shipboard observations, many publications use different size-range categories.

In addition to research activities, the quantification of floating litter is part of the assessment schemes of national and international monitoring frameworks. Monitoring of the quantity, composition and pathways of floating litter can contribute to an efficient management of waste streams and the protection of the marine environment. The European Marine Strategy Framework Directive, national programs, the Regional Sea Conventions and international agreements such as the United Nations Environmental Programme consider the monitoring of floating litter (Chen 2015). Visual assessment approaches include the use of research vessels, marine mammal surveys, commercial shipping carriers and dedicated litter observation surveys. Aerial surveys are often conducted for larger items (Pichel et al. 2012). However, available data for floating litter are currently difficult to compare because existing observation schemes (NOAA, UNEP, Hellenic Marine Environment Protection Association—HELMEPA, etc.) apply different

approaches, observation schemes and category lists (Galgani et al. 2011a, b). Some approaches involve the reporting by volunteers (HELMEPA, Arthur et al. 2011). While the main principle of monitoring floating debris through visual observation is very simple there are not many data sets, which allow a comparison of debris abundance. Some data sets are accessible as peer-reviewed publications or through reports from international organizations. However, the regions covered are very limited and monitoring occurs only sporadically.

Globally, the reported densities of floating marine debris pieces >2 cm ranges from 0 to beyond 600 items km^{-2}. Ship-based visual surveys in the North Sea German Bight yielded 32 items km^{-2} on average (Thiel et al. 2011). The integration over different surveys and seasons resulted in litter densities of 25 items km^{-2} at the White Bank area, 28 items km^{-2} around the island of Helgoland and 39 items km^{-2} in the East Frisian part of the German Bight. More than 70 % of the observed items were identified as plastics. From 2002 to 2006, aerial marine mammals surveys were used for the quantification of floating litter. Results were reported as sightings km^{-1}, ranging from 0 to beyond 1 item km^{-1}. Concentrations in coastal waters appeared to be lower than in offshore regions (Herr 2009).

In the northern Mediterranean Sea, in an offshore area of ca. 100×200 km between Marseille and Nice and also in the Corsican Channel, floating debris was quantified during marine mammals surveys. A maximum of 55 pieces km^{-2} was recorded with strong spatial variability (Gerigny et al. 2011). In the Ligurian Sea, data were collected through ship-based visual observation in 1997 and 2000. Between 15 and 25 objects and between 1.5 and 3.0 objects km^{-2} were found in 1997 and 2000, respectively, without specification of the size ranges used (Aliani and Molcard 2003). Voluntary surveys through HELMEPA made from commercial shipping vessels in the Mediterranean Sea revealed a concentration of 2 items km^{-2} with higher concentrations in coastal areas but also longer transects without any litter encounters. While plastic material accounted for the highest proportion (83 %) of litter, textiles, paper, metal and wood comprised 17 % (UNEP 2009). No size ranges were given, but the described conditions during observation indicate that only larger items were considered. A large-scale survey in the Mediterranean Sea found 78 % of the observed objects larger than 2 cm to be of anthropogenic origin (Suaria and Aliani 2014). Plastic constituted 96 % of these. While highest densities (>52 items km^{-2}) were reported from the Adriatic Sea and Algerian basin, lowest densities (<6.3 items km^{-2}) were recorded in the central Thyrrenian and Sicilian Sea. Densities in other areas ranged between 11 and 31 items km^{-2} (Suaria and Aliani 2014).

Visual aerial surveys were conducted in the Black Sea, flying slow at low altitude above the Kerch Strait, the southern part of the Azov Sea and on the coastal Russian Black Sea. Concentrations in the Kerch Strait and the Azov Sea were comparable at 66 items km^{-2} and twice as high as those from the Black Sea (BSC 2007).

In a visual observation study in the north Pacific, ca. 56 km off Japan, Shiomoto and Kameda (2005) found densities of 0.1–0.8 items km^{-2} at a size >5 cm.

A study at the east coast of Japan utilized surface trawl nets for sampling on transects of 10 min at 2 knots with a net opening of 50 cm and a mesh size of 333 μm. The size of plastic pieces captured ranged from 1 to 280 mm. Pieces >11 mm accounted only for 8 % and particles of 1–3 mm accounted for 62 % at total average litter mass of 3600 g km^{-2} (Yamashita and Tanimura 2007).

Visual observation studies in southern Chilean fjords revealed 1–250 items km^{-2} >2 cm during seven oceanographic cruises from 2002 to 2005 (Hinojosa and Thiel 2009; Hinojosa et al. 2011; Thiel et al. 2013). Typically, densities in the northern areas ranged from 10 to 50 items km^{-2}. Matsumara and Nasu (1997) reported 0.5 items km^{-2} in the waters northwest of Hawaii, close to the so-called Pacific garbage patch, compared with 9 pieces km^{-2} in southeast Asia. Debris densities in the waters off British Columbia (Canada), comprised 0.9–2.3 pieces km^{-2} with a mean of 1.5 items km^{-2} (Williams et al. 2011), but no size range was given. In the Gulf of Mexico, Lecke-Mitchell and Mullin (1997) recorded 1.0–2.4 pieces km^{-2} during cetacean survey flights (Table 2.2).

FMD density in the northern South China Sea was quantified by net trawls at 4.9 (0.3–16.9) items km^{-2}, with Styrofoam (23 %) and other plastics (45 %) dominating (Zhou et al. 2011). More than 99 % of FMD was small- (<2.5 cm) or medium-sized (2.5–10 cm). Large items (10–100 cm) were detected by visual

Table 2.2 Comparison of mean litter densities on the sea surface from worldwide data (non-exhaustive list)

Region	Density (item km^{-2}) (max)	Size range (cm)	Plastic (%)	References
North Sea	25–38	>2	70	Thiel et al. (2011)
Belgian coast	0.7	n.d.	95	Van Cauwenberghe et al. (2013)
Ligurian coast	1.5–25	n.d.	n.d.	Aliani and Molcard (2003)
Mediterranean Sea	10.9 → 52 (194.6)	>2	95.6	Suaria and Aliani (2014)
North Sea	2 (1–6)	n.d.	n.d.	Herr (2009)
Kerch Strait/Black Sea	66	n.d.	n.d.	BSC (2007)
Chile	10–50 (250)	>2	>80	Hinojosa and Thiel (2009)
West of Hawaii	0.5	0.08 (0.2)	n.d.	Matsumura and Nasu (1997)
British Columbia	1.48 (2.3)	n.d.	92	Williams et al. (2011)
South China Sea	4.9 (0.3–16.9)	<2.5–10	68	Zhou et al. (2011)
North Pacific	459	2	95	Titmus and Hyrenbach (2011)
Strait of Malacca	579	>1–2	98.8	Ryan (2013)
Bay of Bengal	8.8	>1–2	95.5	Ryan (2013)
Southern Ocean	0.032–6	>1	96	Ryan et al. (2014)

observation resulting in mean concentrations of 0.025 items km^{-2} (Zhou et al. 2011). In the northeast Indian Ocean, Ryan (2013) reported a large difference in the concentration of marine debris between the Strait of Malacca (578 ± 219 items km^{-2}) and the Bengal Sea (8.8 ± 1.4 items km^{-2}). By contrast, Uneputty and Evans (1997) reported concentrations >375 items km^{-2} in Amon Bay, east Indonesia.

In 2009, a 4,400-km cruise from the American west coast to the North Pacific subtropical gyre and back to the coast provided data during 74 h of observation corresponding to a transect length of 1,343 km (Titmus and Hyrenbach 2011). A single observer at 10 m above the sea level recorded a total of 3,868 pieces, of which 90 % were fragments and 96 % of these were plastic. Eighty-one percent of the items had a size of 2–10 cm, 14 % of 10–30 cm and 5 % of >30 cm. The density of debris increased towards the centre of the gyre where smaller, probably older and weathered pieces were found. The authors note that visual observations are constrained by the inability to detect smaller fragments (<20 mm) and to retrieve the observed items for further analysis and concluded that visual observations can be easily conducted from ships of opportunity, which provide a useful and inexpensive tool for monitoring debris accumulation and distribution at sea.

A specific case of floating marine litter is abandoned or lost fishing gear, such as nets or longlines. These items cause significant harm when abandoned, as they continue to catch marine wildlife (Kühn et al. 2015). In 2003, a major effort, including the identification of possible accumulation areas by satellite imaging and ocean current modelling, was made to select appropriate areas for aerial surveys in search for abandoned fishing gear in the Gulf of Alaska (Pichel et al. 2012). Employing a wide range of methodologies including visual video, infrared video and Lidar imaging during 14 days of observation, 102 items of anthropogenic origin were sighted.

Modelling of oceanographic currents can help to identify pathways and accumulation areas, thus enabling source attribution (Martinez et al. 2009; Maximenko et al. 2012). A modelling approach in the North Sea identified seasonal signals in litter reaching the coasts (Neumann et al. 2014). The concentrations and distribution patterns of floating marine debris can be expected to change according to climatic changes (Howell et al. 2012). Lebreton et al. (2012) modelled the global oceanic currents in view of the cycling and distribution of introduced debris. Input scenarios were based on population density and major shipping lanes. A 30-year projection showed the accumulation of floating debris in ocean gyres and enclosed seas. These studies have the potential to investigate pathways and to guide monitoring to enable effective implementation of management measures and the assessment of their efficiency. Modelling is also used to predict the pathways and impacts of large quantities of debris introduced through natural events such as tsunamis and related run-offs (Lebreton and Borrero 2013). Single events may drastically increase local debris concentrations. A study combining available worldwide data with a modelling approach estimated the weight of the global plastic pollution to comprise 75 % macroplastic (>200 mm), 11 % mesoplastic (4.75–200 mm), and 11 and 3 % in two microplastic size classes, respectively (Erikssen et al. 2014).

The data suggest that a minimum of 233,400 tons of larger plastic items are adrift in the world's oceans compared to 35,540 tons of microplastics.

Floating marine litter can be considered as ubiquitous, occurring even in the most remote areas of the planet such as the Arctic (Bergmann and Klages 2012). Floating litter items are also present in the remote Antarctic Ocean, although densities are low and cannot be expressed as concentrations (Barnes et al. 2010). Some 42 % of the observed 120 objects south of 63°S consisted of plastic. Debris items were observed even as far south as 73°S. However, the small number of surveys and low total object counts do not allow for trend assessments. In the African part of the Southern Ocean, 52 items (>1 cm) were recorded during a 10,467 km transect survey, yielding densities ranging from 0.03 to 6 items km^{-2} (Ryan et al. 2014).

The diversity and non-comparability of monitoring approaches used currently hinders a comparison of absolute pollution indicators and spatial or temporal assessments. The development and widespread implementation of protocols for monitoring, such as the ongoing efforts for the implementation of the MSFD (Galgani et al. 2013), could improve the quality of data gathered. Established protocols should be accompanied by training schemes, quality assurance and control procedures. The implementation of standardized protocols in the monitoring of riverine litter may enable source allocation.

Unfortunately, data acquired by NGOs or authorities are often not published in peer-reviewed journals and are therefore not readily accessible. A joint international database would facilitate the collection of such data and improve standardization and comparability. The collection of data, e.g. on-site through tablet computer applications, the standardization of reporting formats and the streamlining of data flows would facilitate data treatment. More easily accessible data sets can then help to prioritize activities and to monitor the success of litter reduction measures.

While monitoring by human observers is a simple and straightforward approach, in particular for large-scale and frequent surveys, automatized approaches are promising. Developing technologies may lead to the use of digital imaging and image recognition techniques for the autonomous large-scale monitoring of litter (Hanke and Piha 2011).

The implementation of international frameworks such as the EU MSFD, Regional Action Plans against Marine Litter and the agreements of the Rio +20 Conference (United Nations 2012) require improvement of data availability and quality and can therefore be expected to provide the basis for coordinated assessments in the future.

2.3.3 Seafloor

Change in the nature, presence or abundance of anthropogenic debris on the seafloor is much less widely investigated than sea surface patterns. Studies typically focus on continental shelves, as sampling difficulties, inaccessibility

and costs rarely allow for research in deeper waters, which accounts for almost half of the planet's surface. Deep-sea surveys are important because ca. 50 % of plastic litter items sink to the seafloor and even low-density polymers such as polyethylene and propylene may lose buoyancy under the weight of fouling (Engler 2012). While acoustic approaches do not enable discrimination of different types of debris on the seafloor except for metals and may not record smaller objects, trawling was considered the most adequate method when taking into account mesh sizes and net opening width (Galgani et al. 2011b) (Fig. 2.1). However, nets were primarily designed to collect specific biota leading to sample bias and underestimation of benthic litter quantities. Therefore, pole trawling has been suggested as the most consistent survey method for the assessment of benthic marine litter (Galgani and Andral 1998), although rather destructive to seafloor habitats because of the scraping of sediments and inhabiting biota. However, trawls cannot be used in rocky habitats or on hard substrates and they do not allow for a precise localization of individual items. Samples from trawls are likely to underestimate debris abundance and may miss some types of debris altogether such as monofilaments because of variability in the sampling efficiency for different debris items (Watters et al. 2010). Fibres from the trawl nets themselves (Murray and Cowie 2011) may contaminate samples. Finally, it does not enable the assessment of impacts of litter on habitats when it contributes its own impacts on the seafloor, which are more severe for the benthic fauna and habitats than the litter items caught by trawl.

Fig. 2.1 Litter collected by trawling in the Mediterranean Sea, France. 10 min experiment (credit Barbaroux and Galgani, IFREMER)

Strategies to investigate seabed debris are similar to those for evaluating the abundance and composition of benthic species. Mass is less often determined for marine debris, because very large items may increase variability in measures. Although floating debris, such as that found in the highly publicized "gyres" and/or convergence zones, is currently the focus of attention, debris accumulating on the seafloor has a high potential to impact benthic habitats and organisms. Forty-three studies were published between 2000 and 2013. Until recently, only few of them covered greater geographic areas or depths. The majority of these studies utilized a bottom trawl for sampling as part of fish stock assessments. More recently, remotely operated vehicles and towed camera systems were increasingly used for deep-sea surveys (e.g. Pham et al. 2014, see Fig. 2.2).

The geographic distribution of debris on the ocean floor is strongly influenced by hydrodynamics, geomorphology and human factors (Galgani et al. 1996; Pham et al. 2014). Moreover, there are notable temporal variations, particularly seasonal, with tendencies for accumulation and concentration of marine litter in particular
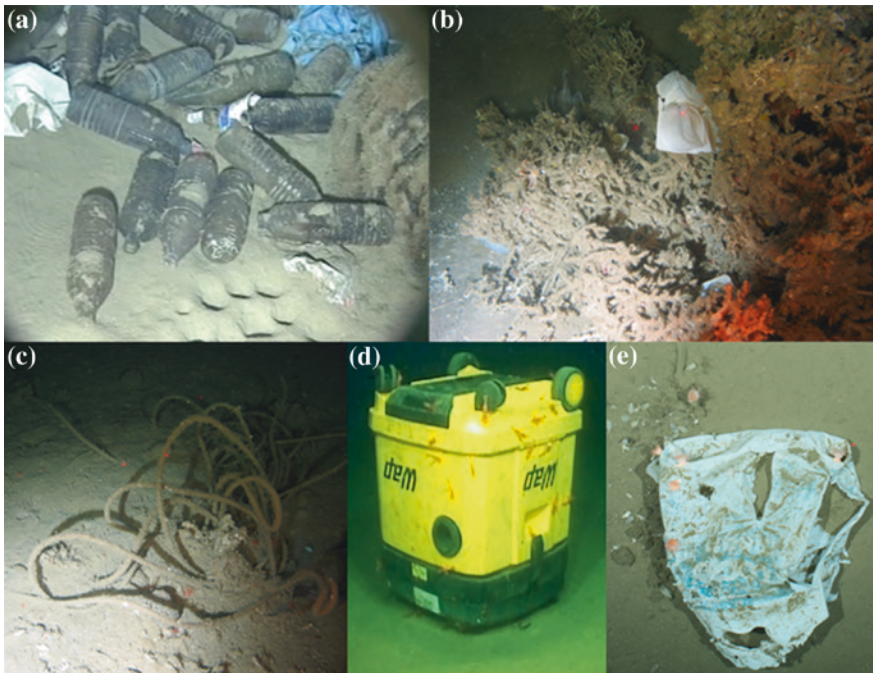
Fig. 2.2 Litter on the deep seafloor. **a** Plastic bags and bottles dumped 20 km off the French Mediterranean coast at 1,000 m in close vicinity to burrow holes (F. Galgani, IFREMER); **b** food package entrapped at 1,058 m in deep-water coral colony; **c** rope at 1,041 m depth, both from Darwin Mounds (courtesy of V. Huvenne, National Oceanography Centre Southampton (NOCS)); **d** waste disposal bin or a vaccum cleaner with prawns on the seafloor off Mauritania at 1,312 m depth (courtesy of D. Jones, SERPENT Project, NOCS); **e** plastic carrier bag found at ~2,500 m depth at the HAUSGARTEN observatory (Arctic) colonised by hormathiid anemones and surrounded by dead tests of irregular sea urchins (courtesy of M. Bergmann, AWI)

geographic areas (Galgani et al. 1995). Interpretation of trends is, however, difficult because the ageing of plastics at depth is unknown and the accumulation of debris on the seafloor certainly began before scientific investigations started in the 1990s.

In estuaries, large rivers are responsible for substantial input of debris to the seabed (Lechner et al. 2014; Rech et al. 2014). Rivers can also transport waste far offshore because of their high flow rate and strong currents (Galgani et al. 1995, 1996, 2000). Alternatively, small rivers and estuaries can also act as a sink for litter, when weak currents facilitate deposition on shores and banks (Galgani et al. 2000). In addition, litter may accumulate upstream of salinity fronts being transported to the sea later, when river flow velocity is increasing.

Plastics were found on the seabed of all seas and oceans and the presence of large amounts has been reported (Galil et al. 1995; Galgani et al. 2000; Barnes et al. 2009) but remains uncommon in remote areas such as Antarctica, particularly in deep waters (Barnes et al. 2009). So far, sampling has been limited to some dozens of trawls and van Cauwenberghe et al. (2013) and Fischer et al. (2015) found pieces of microplastics in deep-sea sediments from the southern Atlantic and Kuril-Kamchatka-trench area, respectively. Large-scale evaluations of seabed debris distribution and densities are more common in other regions (Galgani et al. 2000). However, these studies mostly involve extrapolations from small-scale investigations mainly in coastal areas such as bays, estuaries and sounds. The abundance of plastic debris shows strong spatial variations, with mean densities ranging from 0 to more than 7,700 items km^{-2} (Table 2.3). Mediterranean sites show the greatest densities owing to the combination of a densely populated coastline, shipping in coastal waters and negligible tidal flow. Moreover, the Mediterranean is a closed basin with limited water exchange through the Strait of Gibraltar. Generally, litter densities are higher in coastal seas (Lee et al. 2006) because of large-scale residual ocean circulation patterns but also because of extensive riverine input (Wei et al. 2012). However, debris that reaches the seabed may have been transported over considerable distances before sinking to the seafloor, e.g. as a consequence of heavy fouling. Indeed, some accumulation zones were identified far from coasts (Galgani and Lecornu 2004; Bergmann and Klages 2012; Woodall et al. 2014, 2015). Accordingly, even in the shallow subtidal abundance and distribution patterns can differ substantially from the adjacent strandlines with plastics being the most important fraction at sea. In general, bottom debris tends to become trapped in areas of low circulation where sediments are accumulating (Galgani et al. 1996; Schlining et al. 2013; Pham et al. 2014). The consequence is an accumulation of plastic debris in bays, including lagoons of coral reefs, rather than in the open sea. These are the locations where large amounts of derelict fishing gear accumulate and cause damage to shallow-water biota and habitats (Dameron et al. 2007; Kühn et al. 2015).

Continental shelves are considered as accumulation zones for marine debris (Lee et al. 2006), however, often with lower concentrations of debris than adjacent canyons because debris is not retained but washed offshore by currents associated with

Table 2.3 Comparison of litter densities on the seafloor from recent data worldwide (non-exhaustive list)

Location	Habitat	Date	Sampling	Depth (m)	Density (min–max)	Plastic (%)	References
Southern China	Benthic	2009–2010	4 trawl (mesh not available)/1 dive	0–10	693 (147–5,000) items km^{-2}	47	Zhou et al. (2011)
France-Mediterranean	Slope	2009	17 canyons, 101 ROV dives	80–700	3.01 km^{-1} survey (0–12)	12 (0–100)	Fabri et al. (2014)
Thyrenian Sea	Fishing ground	2009	6 × 1.5 ha samples, trawl, 10 mm mesh	40–80	5,960 ± 3,023 km^{-2}	76	Sanchez et al. (2013)
Spain-Mediterranean	Fishing ground	2009		40–80	4,424 ± 3,743 km^{-2}	37	Sanchez et al. (2013)
Mediterranean Sea	Bathyal/abyssal	2007–2010	292 tows, otter/Agassiz trawl, 12 mm mesh	900–3,000	0.02–3,264.6 kg km^{-2} (incl. clinker)	n.d.	Ramirez-Llodra et al. (2013)
Malta	Shelf	2005	Trawl (44 hauls, 20 mm mesh)	50–700	102	47	Misfud et al. (2013)
Turkey/Levantin Basin	Bottom/bathyal	2012	32 hauls (trawl, 24 mm mesh)	200–800	290 litter (3,264.6 kg km^{-2})	81.1	Güven et al. (2013)
Azores, Portugal	Condor seamount	2010–2011	45 dives	185–256	1,439 items km^{-2}	No plastic/89 % fishing gear	Pham et al. (2013)
Goringe Bank, NE Atlantic	Gettysburg and Ormonde seamounts	2011	4 ROV dives (124 h video, 4,832 photographs), total distance of 80.6 km	60–3,015	1–4 items·km^{-1}	9.9/56 fishing gear	Vieira et al. (2014)
US west coast	Shelf	2007–2008	1,347 sites (total, trawling, 38 mm mesh)	55–183	30 items km^{-2}	23	Keller et al. (2010)
	Slope	2007–2008		183–550	59 items km^{-2}	n.d.	Keller et al. (2010)
	Slope/bathyal	2007–2008		550–1,280	129 items km^{-2}	n.d.	Keller et al. (2010)
Mediterranean Sea, France	Shelf/canyon	1994–2009 (16 years study)	90 sites (trawls, 0.045 km^2/tow, 20 mm mesh)	0–800	76–146 km^{-2} (0–2,540)	29.5–74	Galgani et al. (2000) and unpublished data

(continued)

Table 2.3 (continued)

Location	Habitat	Date	Sampling	Depth (m)	Density (min-max)	Plastic (%)	References
Japan, offshore Iwate	Trench	Jamstek database	3 dives on 4,861 available,	299–400, 1,086–1,147, 1,682–1,753	15.9 items h^{-1}	42.8	Miyake et al. (2011)
Kuril-Kamchatka area (NW Pacific)	Trench/bathyal plain	2012	20 box cores (0.25 m^2) (Agassiz trawl, camera epi-benthic sledge)	4,869–5,766	60 → 2,000 micro-plastics m^{-2}	(Trawl samples: mostly fishing gear)	Fischer et al. (2015)
Fram Strait, Arctic	Slope	2002–2011 (5 surveys)	One OFOS camera tow year^{-1}, 5 transects (1,427–2,747 m^2)	2,500	3,635 (2002)–7,710 (2011) items km^{-2}	59	Bergman and Klages (2012)
Northern Antarctic Peninsula and Scotia Arc	Slopes/bathyal	2006	32 Agassiz trawls	200–1,500	2 pieces only	1 plastic	Barnes et al. (2009)
Monterey Canyon, California	From margin to abyssal	1989–2011	ROVs, 2,429 km^2 in total	25–3,971	632 items km^{-2}	33	Schlining et al. (2013)
ABC islands, Dutch Caribbean	Sandy bottoms to rocky slopes	2000	24 video transects, submersibles	80–900	2,700 items km^{-2} (0–4590)	29	Debrot et al. (2014)

offshore winds and river plumes. Only few studies have assessed debris below 500 m depth (June 1990; Galil et al. 1995; Galgani et al. 1996, 2000; Galgani and Lecornu 2004; Keller et al. 2010; Miyake et al. 2011; Mordecai et al. 2011; Bergmann and Klages 2012; Wei et al. 2012; Pham et al. 2013, 2014; Ramirez-Llodra et al. 2013, Schlining et al. 2013; Fischer et al. 2015; Vieira et al. 2014); Galgani et al. (2000) observed trends in deep-sea pollution over time (1992–98) off the European coast with an extremely variable distribution and debris accumulating in submarine canyons. Miyake et al. (2011) recorded debris down to 7,216 m depth in video surveys from the Ryukyu Trench. Litter was primarily composed of plastic and accumulated in deep-sea trenches and depressions. Accordingly, several authors (Galgani et al. 1996; Mordecai et al. 2011; Pham et al. 2014) concluded that submarine canyons may act as a conduit for the transport of marine debris into the deep sea. Recent studies conducted in coastal deep-sea areas along California and the Gulf of Mexico (Watters et al. 2010; Schlining et al. 2013; Wei et al. 2012) confirmed this pattern. Also, an analysis of the composition and abundance of man-made, benthic marine debris collected in bottom trawl surveys at 1,347 randomly-selected stations along the US west coast in 2007 and 2008 indicated that densities increased significantly with depth, ranging from 30 items km^{-2} in shallow (55–183 m) to 128 items km^{-2} in the deepest waters surveyed (550–1,280 m) (Keller et al. 2010). Higher densities at the bottom were also found in particular areas such as those around rocks, wrecks as well as in depressions or channels (Galgani et al. 1996). Deep submarine extensions of coastal rivers influence the distribution of seabed debris. In some areas, local water movements transport debris away from the coast to accumulate in zones of high sedimentation. In the case of the Mississippi river, for example, the front canyon was a focal point for litter, probably due to bottom topography and currents (Wei et al. 2012). Under these conditions, the distal deltas of rivers can fan out in deeper waters, creating areas of high accumulation. Many authors (Galgani et al. 1996; Moore and Allen 2000; Wei et al. 2012) show that circulation may be influenced by strong currents occurring in the upper part of canyons, which decrease rapidly in deeper areas resulting in an increased confinement with a litter distribution that seems to be temporally more stable as a consequence.

A great variety of human activities such as fishing, urban development and tourism contribute to the distribution pattern of debris on the seabed. Debris from the fishing industry is prevalent in fishing areas (Watters et al. 2010; Schlining et al. 2013; Vieira et al. 2014). This type of material may account for a high proportion of debris. In the eastern China Sea (Lee et al. 2006), for example, 72 % of debris is made of plastic, mainly pots, nets, *Octopus* jars, and fishing lines. Investigations using submersibles at depths beyond the continental shelf and canyons have revealed substantial quantities of debris in remote areas. Galgani and Lecornu (2004) counted 0.2–0.9 pieces of plastic per linear kilometre at the HAUSGARTEN observatory (2500 m) in the Fram Strait (Arctic). Fifteen items, of which 13 were plastic, were observed during one dive between 5,330 and 5,552 m ('Molloy Hole'), which reflects the local funnel-like topography and downwards directed eddies acting as particle trap. Bergmann and Klages (2012) reported doubled litter quantities between 2002 and 2011 in the HAUSGARTEN area. The accumulation

trends reported in that study raise particular concern as degradation rates of most polymers in deep-sea environments are assumed to be even slower due to the absence of light, low temperature and oxygen concentrations.

2.3.4 Microplastics

Similar to large debris, there is growing concern about the implications of the diverse microparticles in the marine environment, which are particles ≤ 1 µm (Galgani et al. 2012; Thompson et al. 2004). Most microparticles are tiny plastic fragments known as microplastics, although other types of microparticles exist, such as fine fly ash particles emitted with flue gases from combustion, rubber from tyre wear and tear as well as glass and metal particles, all of which constantly enter the marine environment. The abundance and global distribution of microplastics in the oceans appeared to have steadily increased over past decades (Cole et al. 2011; Claessens et al. 2011; Thompson 2015), while a decrease in the average size of plastic litter has been observed over this time period (Barnes et al. 2009). In recent years, the existence of microplastics and their potential impact on wildlife and human health has received increased public and scientific attention (Betts 2008; Galloway 2015; Lusher 2015).

Microplastics comprise a very heterogeneous assemblage of particles that vary in size, shape, color, chemical composition, density, and other characteristics. They can be subdivided by usage and source as (i) 'primary' microplastics, produced either for indirect use as precursors (nurdles or virgin resin pellets) for the production of polymer consumer products, or for direct use, such as in cosmetics, scrubs and abrasives and (ii) 'secondary' microplastics, resulting from the breakdown of larger plastic material into smaller fragments. Fragmentation is caused by a combination of mechanical forces, e.g. waves and/or photochemical processes triggered by sunlight. Some 'degradable' plastics are even designed to fragment quickly into small particles, however, the resulting material does not necessarily biodegrade (Roy et al. 2011). The various sources of microplastics and the pathways into the oceans are summarized in detail by Browne (2015).

In order to understand the environmental impacts of microplastics, many studies have quantified their abundance in the marine environment. One of the major difficulties in making large-scale spatial and temporal comparisons between existing studies is the wide variety of methods that have been applied to isolate, identify and quantify marine microplastics (Hidalgo-Ruz et al. 2012). For meaningful comparisons to be made and robust monitoring studies to be conducted, it is therefore important to define common methodological criteria for estimating abundance, distribution and composition of microplastics (Löder and Gerdts 2015).

Microplastics normally float at the sea surface because they are less dense than seawater. However, the buoyancy and specific gravity of plastics may change during their time at sea due to weathering and biofouling, which results in their distribution across the sea surface, the deeper water column, the seabed, beaches and sea ice (Colton and

Knapp 1974; Barnes et al. 2009; Law et al. 2010; Browne et al. 2010; Claessens et al. 2011; Collignon et al. 2012; Obbard et al. 2014). Until now, only a limited number of global surveys have been conducted on the quantity and distribution of microplastics in the oceans (Lusher 2015). Most surveys focused on specific oceanic regions and habitats, such as coastal areas, regional seas, gyres or the poles (Thompson et al. 2004, Collignon et al. 2012; Rios and Moore 2007). Concentrations of microplastics at sea vary from thousands to hundreds of thousands of particles km^{-2} and latest reports suggest that microplastic pollution has spread throughout the world's oceans from the water column (Lattin et al. 2010; Cole et al. 2011) to sediments even of the deep sea (Moore et al. 2001b; Law et al. 2010; Claessens et al. 2011; Cole et al. 2011; Collignon et al. 2012; Erikssen et al. 2014; Reisser et al. 2013; van Cauwenberghe et al. 2013; Woodall et al. 2014; Fischer et al. 2015). Recently, microplastics were also recorded from Arctic sea ice in densities two orders of magnitude higher than those previously reported from highly contaminated surface waters, such as those of the Pacific gyre (Obbard et al. 2014). This has important implications considering the projected acceleration in sea ice melting due to global climate change and concomitant release of microplastics to the Arctic marine ecosystem.

Time-series data on the composition and abundance of microplastics are sparse. However, available evidence on long-term trends suggests various patterns in microplastic concentrations. A decade ago, Thompson et al. (2004) demonstrated the broad spatial extent and accumulation of this type of contamination. They found plastic particles in sediments from U.K. beaches and archived among the plankton in samples dating back to the 1960s with a significant increase in abundance over time. More recent evidence indicated that microplastic concentrations in the North Pacific subtropical gyre have increased by two orders of magnitude in the past four decades (Goldstein et al. 2013). However, no change in microplastic concentration was observed at the surface of the North Atlantic gyre for a period of 30 years (Law et al. 2010).

Less is known about the composition of microplastics in the oceans. Evidence suggests a temporal decrease in the average size of plastic litter (Barnes et al. 2009; Erikssen et al. 2014). Studies based on the stomach contents of shearwaters (*Puffinus tenuirostris*) in the Bering Sea also indicated a decrease in 'industrial' primary pellets and an increase in 'user' plastic between the 1970s and the late 1990s (Vlietstra and Parga 2002) but constant levels over the last decade (Van Franeker et al. 2011). Similarly, long-term data from The Netherlands since the 1980s show a decrease of industrial plastics and an increase in user plastics, with shipping and fisheries being the main sources (van Franeker 2012).

2.4 Summary and Conclusions

Marine debris is now commonly observed everywhere in the oceans and available information suggests that marine debris is highly dynamic in space and time. However, we need standardized methodologies for quantification and

characterisation of marine litter to be able to achieve global estimates. Litter enters the sea from land-based sources, from ships and other installations at sea, from point and diffuse sources, and can travel long distances before being deposited. While plastic typically constitutes a lower proportion of the discarded waste, it represents the most important part of marine litter with sometimes up to 95 % of the waste, and has become ubiquitous even in remote polar regions. However, trends are not clear with quantities having slightly decreased over the last 20 years in some locations, notably in the western Mediterranean. At the same time no change in litter quantities are evident in the convergence zones from oceanic basins or beaches. In other locations, however, including the deep seafloor, densities have increased.

Accumulation rates vary widely with factors such as proximity of urban activities, shore and coastal uses, wind and ocean currents. These enable the accumulation of litter in specific areas at the sea surface, on beaches or on the seafloor. Before an accurate estimate of global debris quantities can be made, basic information is still needed on sources, inputs, degradation processes and fluxes. For this and because there is considerable variation in methodology between regions and investigators, more valuable and comparable data have to be obtained from standardized sampling programs. In terms of distribution and quantities, important questions concerning the balance between the increase of waste and plastic productions, reduction measures and the quantities found at the surface and on shorelines remain unanswered. Potentially, important accumulation areas with high densities of debris are still to be discovered. It is now clear that managers and policy makers will need to better understand the distribution of litter in order to assess and evaluate precisely the effectiveness of measures implemented to reduce marine litter pollution.

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