Chapter 7.2 Open Ocean Pollution – Floating Plastics

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7.2 Open Ocean Pollution – Floating Plastics

7.2.1 Summary and Key Messages

Plastic enters the marine environment from a wide variety of land and sea-based activities, including directly into the open ocean, but there are no reliable or accurate estimates of the nature and quantities of material involved. The majority of the floating plastic in the open ocean is *likely* to have originated from activities within Large Marine Ecosystems (LMEs) and on land.

Once plastic enters the ocean it can become widely dispersed by ocean currents and winds. The overall distribution of floating plastics in the open ocean is dominated by the influence of the general surface water circulation, with relatively high abundances confined to sub-tropical gyres, large-scale systems of rotating ocean currents. An unknown proportion sinks to the seabed as a result of fragmentation or biofouling.

Larger items of plastic debris have a significant impact on many species of marine organisms (for example: invertebrates, fish, birds, reptiles and mammals), due to entanglement and ingestion. Plastic can also cause significant economic loss and may pose a threat to navigation and human safety, and this may occur at a considerable distance from the point(s) of entry.

Plastics fragment as a result of several factors, especially UV irradiation, but retain their original properties. Very little is known of the actual effects of microplastics on marine organisms but a separate assessment of potential effects has been carried out, in parallel, by a GESAMP Working Group (GESAMP 2015).

There is a general lack of reliable and consistent observational monitoring data on floating plastics in the open ocean. This prevents reliable quantitative estimates of the amount of micro- (<5 mm in diameter) and macro- (>5 mm in diameter) plastics in both space and time, especially where the size of particles effectively sampled is unknown and where differences exist in the sampling methods used. Even where good time-series datasets exist, the significant inherent heterogeneity in distribution, at a range of space- and time-scales, has prevented the detection of trends over time, within a defined ocean region, such as a sub-tropical gyre.

The complex nature of multiple sources and effects poses difficulties in designing and implementing cost-effective measures to reduce inputs. In most cases, solutions will need to be multi-agency, multi-sector, regional and international, and require a significant change in public perceptions and attitudes, to be fully effective.

7.2.2 Main Findings, Discussion and Conclusions

Plastics (for example: petroleum-based polymers) started to be produced and used on a large scale in the 1950s. Since, there has been an almost exponential increase in use, as plastics have replaced traditional materials, such as metal, glass and wood, and aided the development of completely new products, such as computers. The most characteristic property of plastic is its durability. This, combined with lightness, excellent barrier properties and low cost, has led to the rapid expansion in use. There are six main polymers in production, but their properties are expanded by the inclusion of a range of additive substances, for example to improve UV resistance, plasticity, colour, impact-resistance and fire retardation.

There has been much discussion about the quantities of marine debris in the environment, where this material originates from and the route by which it reaches the ocean (Ryan et al. 2009, Cozar et al. 2014, Eriksen et al. 2014). Part of the difficulty in ascribing origin to marine plastic is that a significant proportion may be fragmented and difficult to identify. The ability to develop and implement targeted and effective mitigation and adaptation strategies, to reduce the quantities of litter entering the marine environment, will be severely compromised if key sources cannot be identified. In beach surveys, 'consumer waste' often makes up the greatest number of items identified. While consumer waste is undoubtedly a major source of marine litter, including plastic, it would be a mistake to underestimate the importance of other categories (for example: shipping, fisheries and aquaculture) that may represent an equal or greater risk to the marine environment in many regions.

Because of the difficulty and expense of data collection there are generally far fewer observations of floating litter, compared with shoreline litter, and even fewer observations of water column and seabed litter. However, away from the beach, the categories and relative proportions of marine litter tend to be quite different. For example, in those offshore studies that have been reported there tends to be a higher proportion of fishing-related debris, especially on the seabed (Pham et al. 2014).

Plastics fragment when exposed to UV irradiation, especially at higher temperatures and oxygen levels (Andrady 2011). This is greatest on tropical beaches but decreases rapidly at depth in the water column.

Sources can be described as predominantly land-based or sea-based. Some of the most important sources can be categorised as follows:

Land-based

- Coastal tourism/recreation
- Population centres
- Poorly controlled/illegal waste sites
- Industrial sites
- Agriculture
- Natural catastrophes (storms, floods and tsunamis)Sea-based
- Merchant shipping
- Cruise ships
- Fisheries/aquaculture
- Recreational boating
- Offshore oil & gas platforms

Land-based plastic may be transported to the ocean by water and wind. The same sources of litter tend to recur globally, but the relative importance of each source shows significant regional differences, corresponding to the degree of infrastructure development, the principle maritime or coastal industries and the extent of coastal tourism. Along busy shipping lanes, such as the southern North Sea and the Mediterranean, shipping-related debris is more prevalent. Equally, regions subject to intensive aquaculture or fisheries have a proportionately higher incidence of litter directly related to those activities. For example, fragments of expanded polystyrene from floatation blocks are common in the coastal waters of Korea, Japan and Chile where aquaculture is abundant. Cultural differences can influence the input of certain types of litter, such as the readiness to flush sanitary items with domestic sewage waste.

Once in the sea, floating litter is transported by ocean currents and rapidly becomes a transboundary issue. An unknown proportion sinks to the seabed either due to the inherent density of the plastic, once air has been excluded or due to an increase in density caused by biofouling (Holmström, 1975). The economic model used over the second half of the 20th century has been largely linear: raw materials –> manufacture –> use –> disposal. This is unsustainable in the longer term. It also relies on very effective systems for dealing with waste. Unfortunately, these are inadequate in many parts of the world. Poor waste management, combined with inappropriate use, unhelpful public attitudes and irresponsible behaviour, is the principal reason why plastic enters the marine environment.

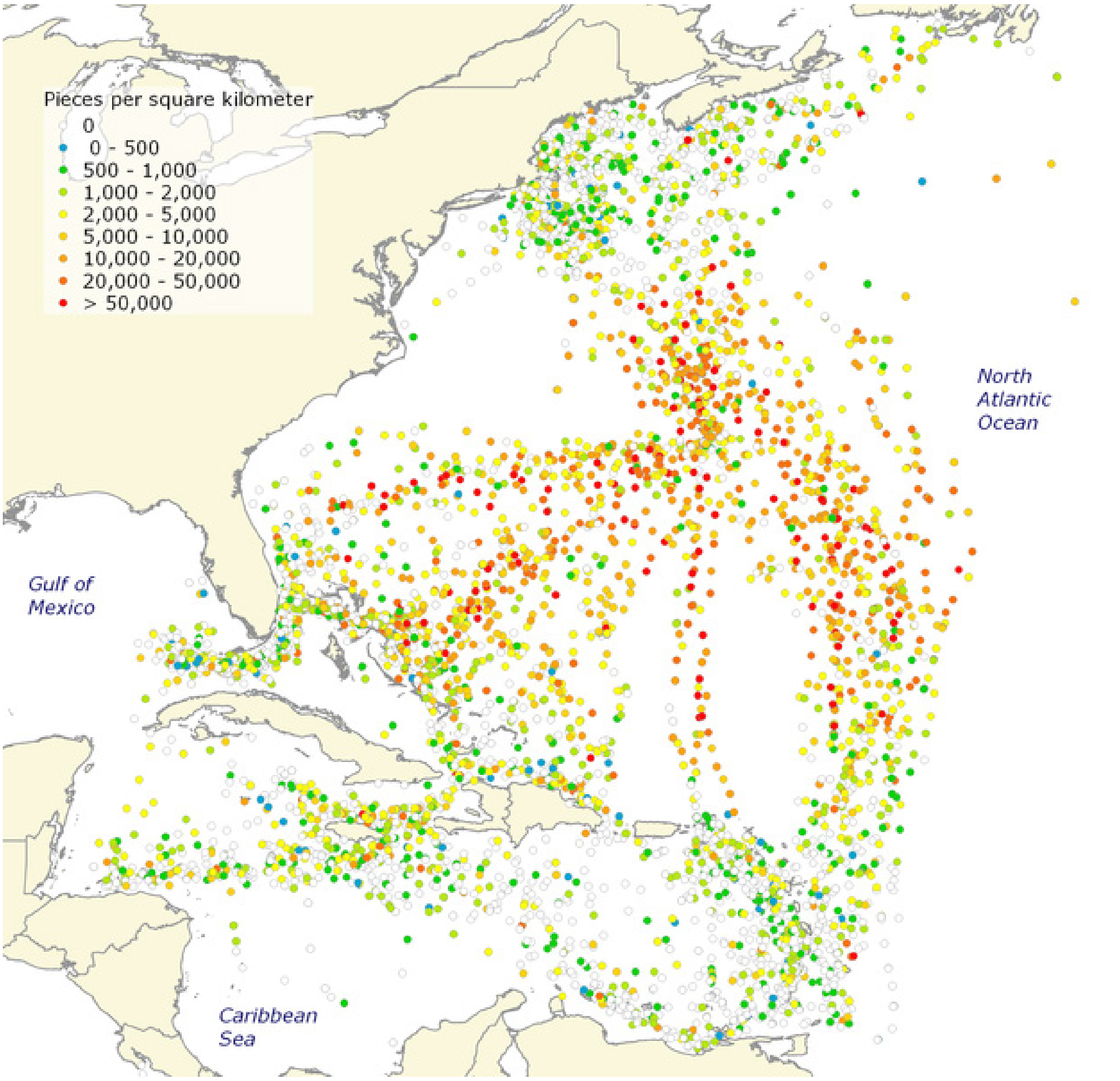
Floating plastics occur across a very wide size spectrum, from items several metres in diameter to nano-sized particles (<0.1 mm). There has been increasing interest in the occurrence of microplastics within the past decade. The term 'microplastics' was coined quite recently, in the mid-2000s (Thompson et al. 2004) and is now used extensively. However, there is a lack of consensus on the size of particles this refers to. Polymer spheres and irregular-shaped particles in the nano- to micro- size ranges are used in a wide variety of applications, including printer inks, spray paint, injection mouldings and personal health products such as toothpaste. Plastic resin pellets are produced as the basis for that part of the industry that converts these basic polymers into the enormous variety of goods on which modern society depends. These are typically spherical or cylindrical 1-5 mm in diameter, and there have been many reported incidents of accidental release on land and at sea. Efforts by industry to improve the handling of plastic pellets have brought about a decrease in the quantity of pellets in the environment (Ryan 2008).

Plastics have been shown to injure or kill many species of marine organisms (fish, birds, reptiles, mammals, invertebrates) by ingestion or entanglement. Floating plastic can cause significant loss of income to some social groups, such as fishers, and pose a hazard to navigation (for example: by blocking cooling water intakes on ships and fouling propellers).

Findings

The Sea Education Association (SEA) has collected zooplankton using towed nets in the western North Atlantic for many years. References to floating plastic micro-litter appeared in cruise reports from the early 1990s, although there are published records from the 1970s by other workers. The SEA began to systematically re-analyse archived zooplankton samples for the presence of microplastics and published a 20-year summary in 2010 (Morét-Ferguson

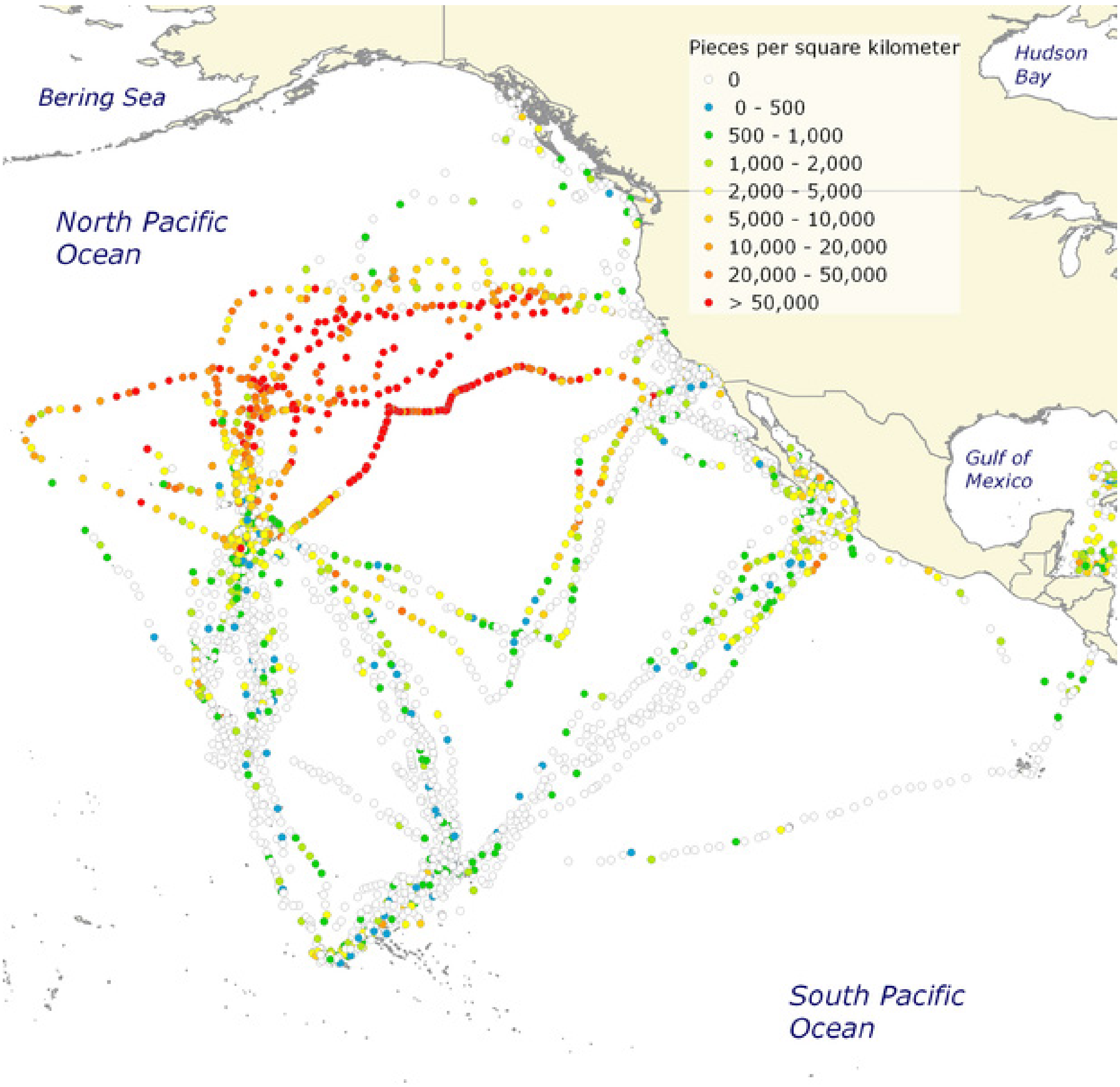
Figure 7.1. Density of floating microplastics (pieces km^{-2}) per year , from Sea Education Association expeditions to the western North Atlantic, 1986-2008 (see http://onesharedocean.org/open_ocean/pollution/floating_plastics)



et al. 2010). This represents the most comprehensive spatial and temporal survey in the global ocean, and clearly showed the overwhelming influence of the North Atlantic Gyre circulation. Most of the Atlantic and Pacific data are available for download (http://www.marine-geo.org/tools/search/entry.php?id=Pacific_Law).

The SEA has also been active in the eastern North Pacific and a similar 11-year dataset of microplastic abundance was published recently (Law et al. 2014). The influence of the sub-tropical gyre is again striking. However, a careful analysis of the data revealed significant differences in recorded abundance due to meso-scale eddies, wind-induced linear convergence zones or 'windrows' (due to Langmuir circulation) and similar features due to internal waves. Repeated year-on-year sampling at the same location failed to reveal a significant trend in abundance, presumably due to the spatial heterogeneity created by this physical forcing. An analysis by other researchers, comparing microplastic data from the period 1972–1987 with 1999 –2010 in the eastern North Pacific, did appear to show an increase in concentration of two orders of magnitude (Goldstein et al. 2012). However, uncertainties remain about the magnitude of the increase due to differences in sampling techniques and sampling strategy.

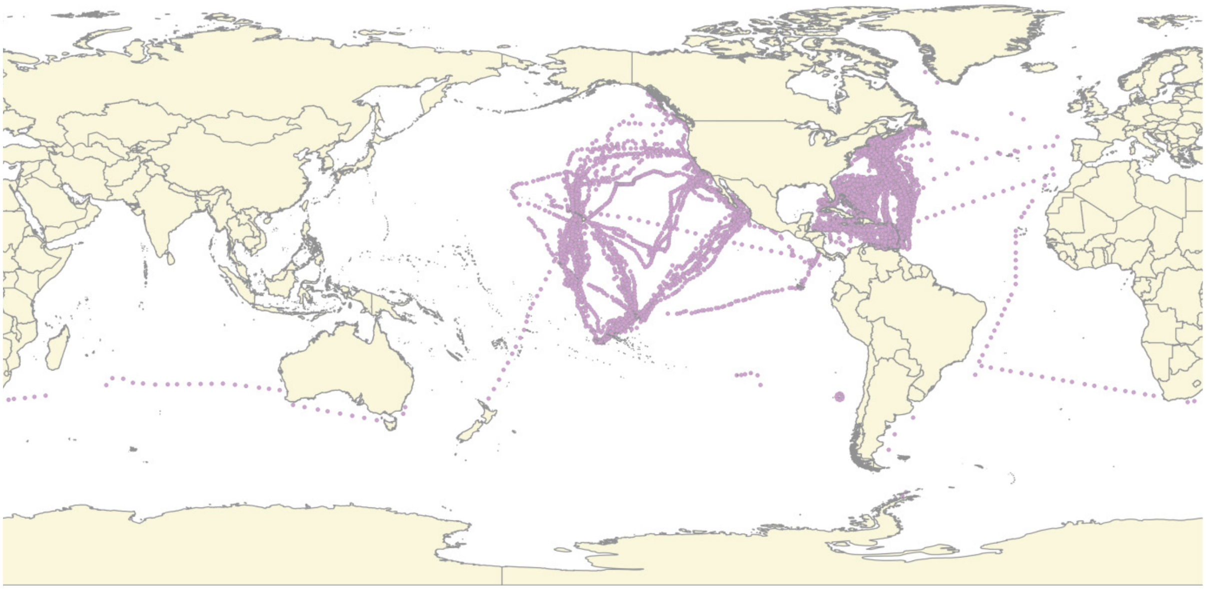
Figure 7.2. Density of floating microplastics (pieces km-2) per year, from SEA expeditions to the western North Pacific, (see http://onesharedocean.org/open_ocean/pollution/floating_plastics)



The 5 Gyres organisation, an NGO, has conducted a number of sailing expeditions in the South Pacific, North and South Atlantic and Indian Oceans (Eriksen et al. 2013; Eriksen et al.2014). These usually provide single transects but this still represents a valuable source of information from ocean regions that may not be visited regularly by more conventional research vessels. The Algalita Marine Science Association has helped raise awareness of marine litter, organising a number of expeditions in the eastern North Pacific to sample for microplastics. Algalita promoted the term 'North Pacific Garbage Patch' to describe the accumulation of plastic debris in the North Pacific Gyre. This had the unintended consequence of being translated in the media and public conscience to mean a floating island of waste material, variously described as being the size of Texas, or some other arbitrary unit of area depending on the national origins of the writer. This is far from reality.

A collation of the most comprehensive datasets was compiled by the TWAP group to produce a five-year 'synoptic' overview of the current status of the open ocean with respect to floating microplastics in surface waters (for example: plastic debris collected in a 330 µm towed net). A similar analysis of floating micro- and macro-debris, largely utilising previously unpublished data from 24 expeditions, was published in December 2014 (Eriksen et al. 2014),

Figure 7.3. Sampling locations for floating microplastics, compiled from published sources



Debris has been found washed ashore in the remote islands of the Pacific, Atlantic, Indian and Southern Oceans. This includes fishing gear, household items and microplastics. Such data provide the most reliable source of information about sources and trends, although they are not readily translated into '*items km*$^{-2}$' of the ocean surface. Observations of macro- and micro-plastics have been made in the Southern Ocean, despite the remoteness and difficulty of sampling in this environment (Barnes et al. 2010). These have included sea-based and shoreline observations, including the effects on local fauna (Ivar do Sol et al. 2011).

One of the consequences of catastrophic natural events, such as hurricanes and tropical storms (for example: Katrina, USA, 2005; Sandy, USA, 2012; Haiyan/Yolanda, Philippines, 2013), river basin flooding (for example: Bangkok, Thailand, 2011) and tsunamis due to seismic activity (for example Sumatra-Andaman earthquake & Indian Ocean tsunami, 2004), is that large quantities of debris can suddenly be introduced in coastal waters. This includes anthropogenic materials such as plastics, and the issue has come to prominence following the enormous devastation and human tragedy of the great Tohoku tsunami along the east coast of Japan on 11 March 2011. The Japanese government estimated that 5 million tons of debris entered the ocean, of which 70 per cent is thought to be lying on the seabed, leaving 1.5 million tons of floating material. This varies enormously in size and composition, ranging from floating docks and ships to household artefacts and the smallest items of litter. An unknown proportion will be composed of plastic. Monitoring using a mix of satellite, over-flight, ships' sightings and beach observations has helped to track the progress of the debris field. The distribution of floating plastic from this single event will continue to evolve for many decades to come.

Model simulations have proved to be very useful in predicting the transport pathways and transit times of debris fields from accidental releases and catastrophic events (Lebreton and Borroro, 2013). These range from plotting the distribution of cargo from individual stricken vessels, to large-scale events such as tsunamis. This can assist in evaluating potential navigation hazards as well as predicting when material can be expected to be start appearing on beaches (http://marinedebris.noaa.gov/tsunamidebris/). The HYCOM/NCODA model (Hybrid Coordinate Ocean Model/Navy Coupled Ocean Data Assimilation) was also used to provide an estimate on the global quantity of floating plastic based on the observed distribution of micro and macroplastic. It was estimated that there were more than 5 x 10^{12} pieces of floating litter, with a mass of 250,000 tonnes (Eriksen et al. 2014).

Modelling has also been used to simulate the input and transport of plastics from a number of sources. A group based in Australia and the USA combined the HYCOM/NCODA ocean circulation modelling system with the particle tracking dispersal model PoL3DD (Lebreton et al. 2012). Instead of assuming a uniform starting condition, as adopted by previous efforts (IPRC 2008), the team used three particle input scenarios: i) an impervious watershed, as a proxy for the input of debris as it relates to the degree of urbanisation and runoff; ii) coastal population density; and iii) shipping density. In year one, 100 000 particles were released and this was increased linearly, with 9.6 million particles being released over the 30 year simulation.

This revealed an apparently similar relative distribution of particles for each scenario, with higher quantities in the northern hemisphere due to the higher intensity of human population and shipping pressures. However, a more detailed examination of the data indicated significant differences in the relative importance of the three pressures represented by the scenarios chosen, in different accumulation zones.

Once plastic enters the sea the surface is rapidly colonised with biofilms (Zettler et al. 2013) and larger sessile organisms may become established. In time a new microcosm is created and this may be utilised by other organisms as a refuge, for feeding or reproduction (Barnes and Milner 2005; Goldstein et al. 2012). Rafting of organisms on floating debris is a natural phenomenon, but the increase in the number of floating items, combined with the durability of plastic, may represent a vector for the transport of non-indigenous species. This has been of particular concern in the USA and western Canada in the aftermath of the Tohoku tsunami.

Discussion and Conclusions

The social, economic and ecological impacts of macro-scale debris, especially plastic litter, have been clearly demonstrated, although it is difficult to quantify this in terms of monetary value or ecological significance. Plastic litter can have a direct impact on shipping as a navigation hazard, for example by cooling water intakes becoming blocked or propellers fouled. Many species have been shown to suffer injury and death from both entanglement and ingestion of larger debris, although it has proved more difficult to demonstrate this for microplastics.

Studies have shown that micro-particles can be ingested by filter-feeding organisms, and these have been observed to cross the gut wall and induce a reaction within the tissue. This is described in more detail in a separate assessment carried out by GESAMP (GESAMP 2015, www.gesamp.org). At a different scale, baleen whales, such as the endangered North Atlantic right whale (*Eubalaena glacialis*), feed on copepods and other small invertebrates by filtering enormous volumes of seawater. It is not known whether the presence of microplastics presents a potential additional stressor by clogging the baleen.

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Debris acts as vector for the transport of non-indigenous species (NIS). Because plastic does not degrade readily, unlike natural debris such as plant material, the potential distance over which NIS may be transported could be much greater.

Providing a clearer picture of the spatial distribution of macro- and micro-sized plastics, and the physical processes responsible for their transport, will allow potential management measures to be more clearly targeted. For example, this approach has been applied in the design of conservation measures to protect turtle populations off the coast of northern Australia from derelict fishing gear (Wilcox et al. 2014).

Some plastics contain additives to achieve certain properties (for example: flexibility, UV resistance, flame retardation), which have potential eco-toxicological impacts. What is not known with enough certainty is the degree to which this represents a potential exposure pathway. Even if there is some transfer from a particle into an organism, is this at a level that will result in a significant impact?

Seawater is contaminated with a wide variety of organic and inorganic pollutants. Many plastics absorb organic contaminants, such as PCBs (polychlorinated biphenols) and the pesticide DDT (dichlorodiphenyltrichloroethane), to a high degree. These compounds can cause chronic effects such as endocrine disruption, mutagenicity and carcinogenicity. They penetrate the structure of the plastic and it can take tens to hundreds of days to reach equilibrium with the surrounding seawater. Once ingested, the compounds may start to leach out, but the rate and direction of transfer will depend on the chemical environment in the organism's gut and the existing levels of those compounds in the tissue. Organisms become contaminated by contact with their environment and by ingesting contaminated food. Separating the potential additional contaminant burden due to microplastics remains extremely problematic.

Recommendations

As a result of discussions during the preparation of this report the contributors agreed a series of recommendations to improve the effectiveness of future assessments, including to:

- Encourage the harmonisation of sampling and analysis protocols to allow data on marine litter to be compiled more readily, including the use of automated systems;
- Examine ways of introducing sampling for marine litter as a routine operation on both research vessels and ships of opportunity, especially on regular cruise, ferry or commercial routes;
- Encourage the reporting of observations of marine litter in the water column and on the seabed from commercial fishing activities using towed nets, and from research organisations using nets, Remotely Operated Vessels (ROVs) and other sampling techniques;
- Promote closer working between international bodies (for example: FAO, IMO, UNESCO-IOC, IWC, CBD, ICES, PICES), regional organisations (for example: OSPAR, HELCOM, NOWPAP, MED-POL, Regional Fisheries Management Organisations (RFMOs), European Commission) and commercial bodies (for example: shipping companies), to encourage greater awareness, cooperation and data sharing;
- Maintain the OneSharedOcean.org website to allow the research and wider community make use of this as a continuing data repository and resource; and
- Promote the use of the improved evidence base to encourage the reduction in plastic litter entering the ocean, recognising that effective solutions will need to be supported multi-agency, multi-sector, regional and international efforts.

7.2.3 Notes on Methods

A small group of experts was assembled to examine and review published data on the occurrence of floating macro and microplastics in the ocean. The aim was to collate reliable data to establish spatial and temporal trends. It soon became evident that there was an overall paucity of data for many ocean regions. The first reports of floating litter were published in the early 1970s (Carpenter et al. 1972), but it proved to be very difficult to locate the originators of the study and the current data holders. In addition, there was a lack of detailed information on sampling positions and sampling methodologies.

Data of floating plastic debris have been collected for many decades, but the spatial extent and resolution of observations have increased significantly since 2000. This includes routine monitoring programmes set up at governmental level and ad-hoc surveys, as performed by NGOs. Of these the NOAA Marine Debris Programme (http://marinedebris.noaa.gov /) and the SEA (http://www.sea.edu/plastics/) have produced the most comprehensive datasets, with the North Pacific and North Atlantic sub-tropical gyres being the most studied.

Data on floating plastics are obtained by two main approaches: direct observation of larger items from ships (Ryan 2013); and, sample collection of smaller items using towed nets (Morét-Ferguson et al. 2010). A recent trend has been to try to utilise image recognition software to analyse camera images of larger items floating on the sea surface or of microplastics from on-line water sampling, but these techniques are at an early stage of development. Aircraft and satellite observations have also been used to track debris fields from catastrophic events, such as the great Tohoku tsunami in 2011.

Each method requires certain assumptions to be made about sampling efficiency and representativeness of the observations. This can impose limitations on the degree to which data from different sources can be combined reliably. Recommendations for more harmonised sampling, monitoring and assessment strategies have begun to be published (for example: Lippiat et al. 2013) which should improve the value and reliability of future monitoring data. Shoreline observations provide an additional data source, and are particularly useful in monitoring trends in litter accumulation in regions remote from the input sources, such as mid-ocean islands and at high latitudes (Barnes et al. 2010), although the results are sensitive to the frequency of sampling (Ryan et al. 2014).

Fragments of plastic cover a huge range of sizes, and defining what is and is not a ‘microplastic’ is a matter of debate. Many researchers now use the arbitrary upper size limit of 5 mm; a size that could be considered to be easily ingested by organisms such as fish and smaller seabirds, although for filter-feeding bivalves the size limit tends to be < 1 mm. The quantity of microplastics reported will depend on the size definition and the sampling methods used. The main message is that it is important to state the definition being used in every study.

Microplastics are usually collected using a neuston net or manta trawl, developed for zooplankton sampling, often using a 330 µm mesh and towing in the upper few centimetres. Nets with coarser mesh sizes have been used in some older surveys (for example: 505 µm, Goldstein et al. 2012). In addition, some results are reported by number and some by mass of particles, illustrating the need to re-analyse data from different sources are combined or compared. In addition, wave action can cause floating microplastics to be mixed to depths of several metres, lowering the observed surface concentrations by up to an order of magnitude. Observations of sea state should be made at the time of sampling to help in data interpretation, but this does not appear to have been a routine practice on some sampling campaigns. Such differences in sampling and reporting mean present difficulties when combining or comparing data.

Direct ship-based observations of floating litter have been by several researchers, usually from research vessels or ships of opportunity, and there have been attempts to collate the metadata about some of these published sources. For example, data from ship observations has been collated and compared with recent observations from the Bay of Bengal and Straits of Malacca (Ryan, 2013).

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