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Foresight

Future of the Sea: Plastic Pollution

Foresight – Future of the Sea

Evidence Review

Foresight, Government Office for Science

Future of the Sea: Plastic Pollution

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Contents

Executive Summary

Around 70 per cent of all the litter in the oceans is made of plastic. Pollution of the environment with plastics is a global environmental problem; with plastic debris contaminating habitats from the poles to the equator and from the shoreline and sea surface to the deep sea. Plastic pollution results from a highly heterogeneous mixture of litter types differing in origin, size, shape and polymer type. Some of the most numerous items are discarded single-use packaging together with rope, netting and sewage-related debris. The majority of this litter originates from the land with rivers providing an important pathway to the sea.

Plastic pollution can be harmful to wildlife, human well-being and to the economy in the UK, its Overseas Territories (OTs) and internationally. There is extensive evidence that entanglement in, or ingestion of, plastics can cause injury and death to a wide range of marine organisms, including commercially important fish and shellfish. Plastic pollution is also hazardous for mariners and reduces the amenity value of coastlines necessitating costly ongoing clean-up operations. In addition, there are emerging concerns of potential negative consequences for human well-being, but currently there is a lack of evidence on which to base firm conclusions here. The effects of small particles of micro and nano-sized plastic debris are not fully understood, but these particles could present different types of impact to those described for larger items.

Plastics are persistent contaminants and while there is uncertainty about the absolute quantity currently in the environment, it is clear that in the absence of any actions both the quantity and the associated impacts will increase.

Globally, production of plastics exceeds 300 million tonnes per annum and it is likely that a similar quantity of plastics will be produced in the next eight years as was produced in the whole of the 20th century. It is without question that plastics bring many societal benefits, however it is evident that most of these benefits could be realised without the need for the release of plastics, to the natural environment. Plastic pollution in the sea is a symptom of a more systemic issue originating on land and related to the design, the use and the disposal of plastic items, particularly single-use packaging. To reduce it, a key priority is to focus on interventions and stewardship to help reduce the quantity of plastic waste generated by society and the associated release of litter to the ocean.

1. What are the Key Drivers of Plastic Pollution?

In the marine environment the vast majority of litter is plastic, with items of metal, glass and paper being considerably less abundant (Galgani et al. 2010). These trends are fairly consistent worldwide and, as a consequence, the accumulation of plastic litter has been identified as a major global problem by the United Nations Environment Assembly and in the G7 Leader´s declaration 2015 (GESAMP 2016; Werner et al. 2016). While the focus here is on the marine environment, freshwater habitats are also contaminated with plastic, and rivers provide major pathways of plastics to the ocean (GESAMP 2016).

Plastics are synthetic polymers, the most common being: polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC) polyethylene terephthalate (PET) and polystyrene (PS). They can be made into a vast range of inexpensive, light-weight and durable products that bring numerous societal benefits. This has resulted in an exponential increase in global demand, from around 5 million tonnes in the 1950s to over 300 million tonnes today. Current annual demand in the UK is around 37 million tonnes (Plastics Europe 2015). Some applications of plastics have a long service life, such as PVC and PP components in vehicles or the construction industry. However, around 40 per cent of all the plastic produced is used for packaging, which is predominantly single use (Plastics Europe 2015).These items are frequently made of PE or PET and represent a substantial proportion of the waste managed via landfill, incineration and recycling (Barnes et al. 2009). Single-use items, together with rope and netting, are also the most abundant types of litter found in the marine environment (OceanConservancy 2016; Nelms et al. 2017).

Interactions between society and the environment, such as this, can be described and summarised using the Driver-Pressure-State-Impact-Response (DPSIR) framework (Figure 1). In this regard, an overriding *Driver*, leading to accumulation of litter is the demand for plastic items (Section 1). These include items used in a range of applications, for example in transport, construction and packaging. The associated waste, which is dominated by single-use items, puts *Pressure* on waste management systems. Evidence shows that a combination of ineffective waste capture and ineffective sewage treatment, together with product designs that do not reflect end-of-life scenarios and littering behaviour, all contribute to the release of plastics to the environment. Since plastics are persistent they are accumulating, leading to the current *State* of environmental contamination (Section 2) and this leads to a wide range of *Impacts* (Section 3). In this context, waste can be defined as something of little or no value and hence the problem may be exacerbated by the inexpensive nature of most plastics, which facilitates short-lived applications and can also present an obstacle to the viability of recycling; which is one of the potential solutions or *Responses* that could help reduce the accumulation of plastics (Section 4).

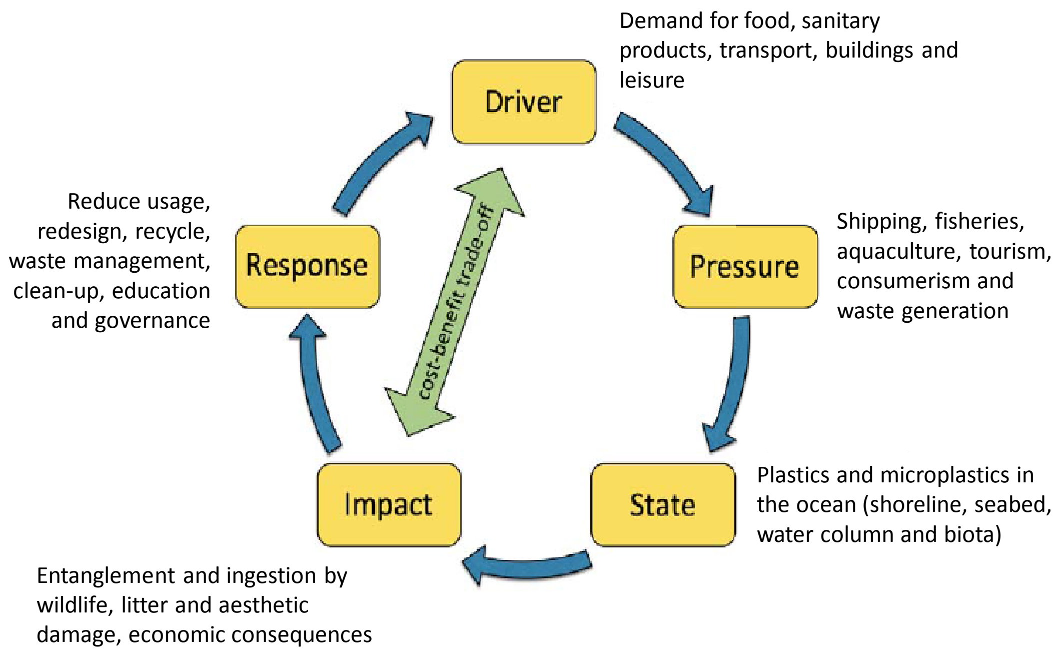

Figure 1. The DPSIR framework in relation to inputs and impacts of plastics and microplastics in the marine environment. Modified from original by P. J. Kershaw (UNEP 2016).

2. What Evidence Exists in the UK, its Overseas Territories & Internationally?

It is clear that plastic debris, including microplastics, now contaminate habitats from shallow water to the deep sea and from the poles to the equator. It is present on shorelines, in the water column, in sediments and in organisms (Barnes et al. 2009; Law & Thompson 2014; GESAMP 2016). The majority of plastics are very resistant to degradation and hence some polymer chemists consider most of the conventional (non-biodegradable) plastics ever produced are still present on the planet unless they have been burned (Thompson et al. 2005). Consequently, the quantity of plastics in the marine environment, as well as the frequency of impacts that are described here will, assuming business as usual, all increase over time.

The items that comprise this litter are extremely heterogeneous in terms of polymer type, size, shape and colour. For instance some discarded or abandoned fishing nets can be 100s of meters in length while microplastic fragments can be just a few micrometres in size (UNEP 2016).

Plastic debris can be defined and described in a variety of ways including by size, shape, colour, polymer type, origin (e.g. from the land, fishing-related or sewage-related debris) and original usage (e.g. packaging, rope). One of the commonly used distinctions is according to size. Here *macroplastics* items are described as items larger than 5mm while *microplastics* are pieces and fragments less than 5mm in one dimension. However, it is important to note that there are no universal conventions on nomenclature and this challenges inter-comparability of data. Items of macroplastic debris are often sufficiently recognisable to be categorised according to their original usage. Attributing sources of microplastics is more challenging, however; it is widely acknowledged that they can arise from the fragmentation of the larger plastic items as well as the direct release of small particles to the environment, for example microbeads released from cosmetics (Napper et al. 2015; Figure 2). It seems likely that even smaller nanoplastic particles also occur in the environment, but it is not currently feasible to separate and identify plastic particles of this size from complex environmental mixtures (GESAMP 2016; Koelmans et al. 2016).

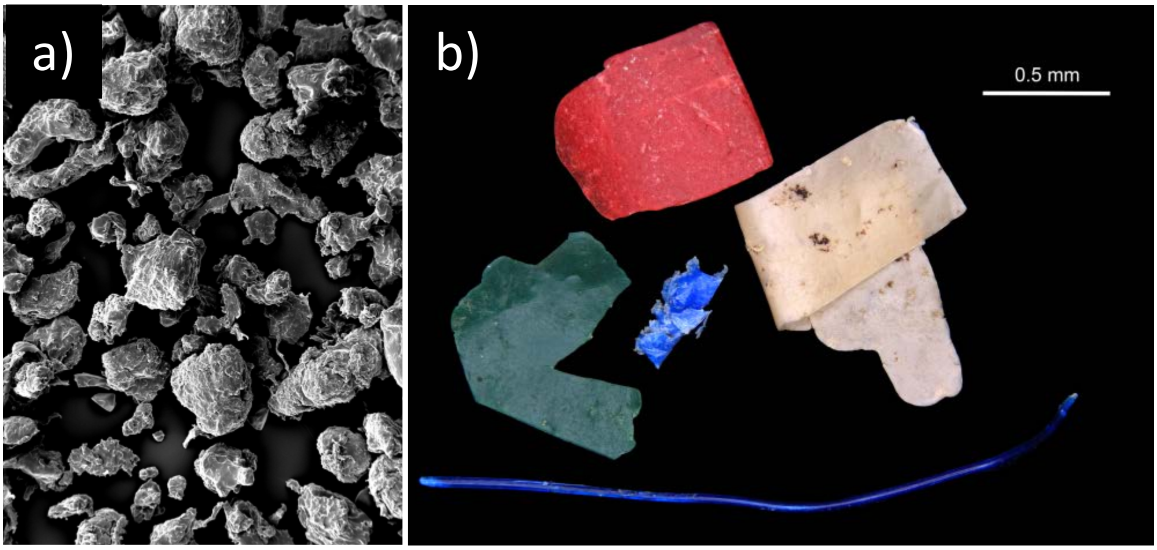

Figure 2. Microplastics.
a) polyethylene particles extracted from a cosmetic product.
Source: Napper & Thompson, Plymouth University Electron Microscopy Suite.
b) fragments of microplastic collected from a shoreline near to Plymouth, UK.
Source: Thompson, Plymouth University.
Note: Scale bar applies to both pictures.

The potential for plastics to escape waste management is exacerbated by the diversity of uses which result in a wide range of potential points of entry to the environment, including agriculture, aquaculture, fisheries, tourism, construction, transport and domestic consumers (UNEP 2016; Figure 3). Recent evidence also indicates that atmospheric transport of plastic dust provides a further pathway for particles and fibres less than 1mm in size (Dris et al. 2015). Such complexity together with the heterogeneous range of litter types present a considerable challenge when trying to identify trends in abundance (MSFD GES Technical Subgroup on Marine Litter 2011).

There have been several attempts to quantify the amount of plastic in the ocean on a global scale, but there is a lack of consensus and it has been suggested that there may be as yet unidentified environmental sinks where substantial quantities of plastics have accumulated (Law & Thompson 2014; Thompson et al. 2004). A study modelling mismanaged plastic waste discharged from the land estimated annual inputs to the ocean of 4.8–12.7 million tonnes of plastics globally (10,000–27,000 tonnes in the UK). An alternative approach is to use empirical counts of litter at sea to describe the abundance of specific types of litter in particular environmental compartments. For example, based on data collected from net tows, Cozar et al. estimate 7,000–35,000 tonnes small (approximately 25mm or less) debris at the sea surface

(Cozar et al. 2014), while van Sebille et al. estimate 93,000–236,000 tonnes, equivalent to 15–51 trillion small particles (van Sebille et al. 2015). The discrepancies between these figures arise from differences in the method of estimation. A further approach is to estimate inputs of specific categories of litter. For example, based on daily UK usage, it was estimated that a specific type of product, facial scrubs, could lead to release of 86 tonnes of microbeads (Figure 2a) to the environment per annum (Napper et al. 2015).(Napper et al. 2015).

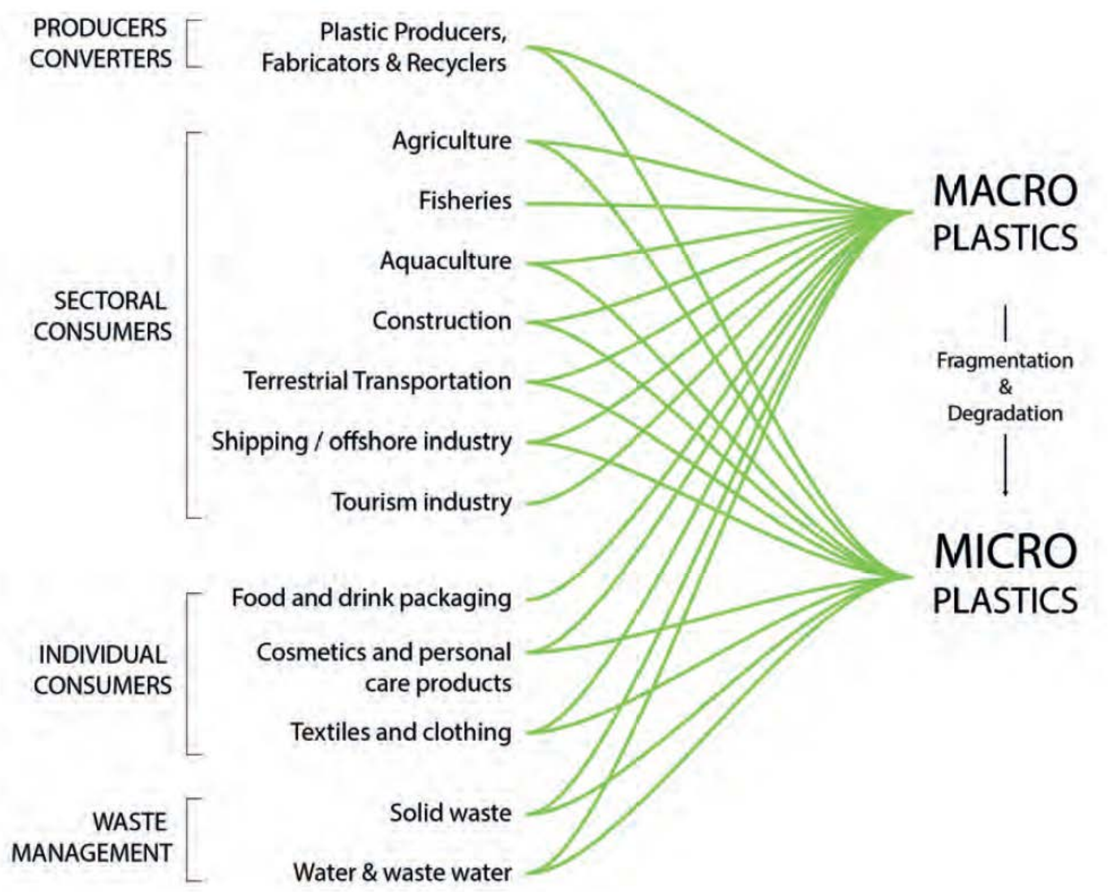

Figure 3. Potential sources of microplastics to the marine environment.
Source: GESAMP (2016).

At a finer scale, at locations that have been the focus of individual surveys, there is a clearer picture of levels of contamination (Figure 4), yet comparison between locations and sampling dates is often hindered by differences in methodology.

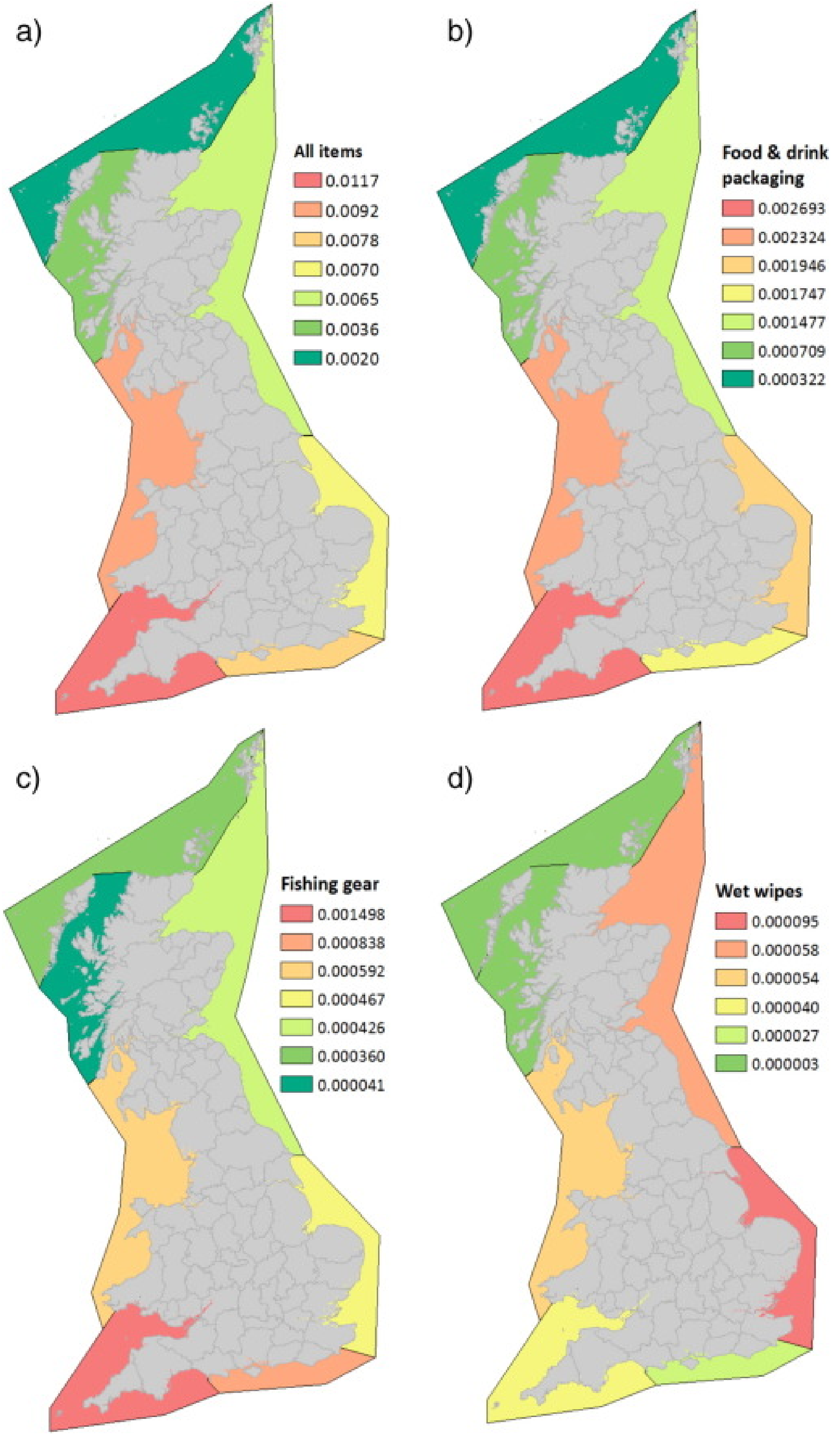

Figure 4. Distribution maps of regional mean number of items m^{-1} min^{-1} $person^{-1}$ (dark green = low number of items, red = high number of items), for a) all litter items, b) food and drink packaging, c) fishing gear, and d) wet wipes. While patterns are standardised for sampling effort, there was considerably less sampling, and hence greater uncertainty in the data, in the north of Scotland compared to other areas.

For full details see Nelms et al. (2017).

Analysis of 3,245 beach cleans undertaken by volunteers between 2005 and 2014 showed that plastics accounted for around 80 per cent of the litter on UK shores and that the majority had originated from land-based sources with some of the most frequently reported items being packaging (Appendix I). The western English Channel and Celtic Sea exhibited the greatest abundance of food and drink packaging and fishing-related debris, as well as having the greatest abundance of items overall (Figure 4 a, b, c) whereas the southern North Sea had the greatest abundance of wet wipes, a category of sewage-related debris (Figure 4 d). Sewage-related debris typically enters the environment when it is not adequately intercepted by sewage treatment facilities; for example when very heavy rainfall results in a sewage overflow. The underlying causes for the higher levels of contamination in south-west Britain probably include a number of factors: the presence of large cities together with rivers facilitating discharge (Swansea, Newport, Bristol and Plymouth), tourism, high levels of fishing effort and busy shipping routes, coupled with wind-driven litter transport in a generally westerly direction from the Atlantic. This analysis did not detect a change in total litter abundance over time, however some specific categories of litter (plastic fragments, polystyrene foam, fishing net, balloons, wet wipes, food packaging) showed significant increases. None of the most common items showed a decrease in abundance (Nelms et al. 2017).

Compared to shorelines there are fewer data from the sea bed or the sea surface. In the North Sea, data from seabed trawls indicate the extensive distribution of plastic litter on the continental shelf (van Hal 2015; Figure 5). While data from the deep sea, including several areas in the northeast Atlantic, indicate substantial accumulations of macroplastics (Galgani et al. 2000) and microplastics (Woodall et al. 2014). Sea surface data for microplastics show clear spatial patterns with high abundance in the central Atlantic as opposed to coastal waters (Law et al. 2010). Data on temporal change are limited since there are few long-term studies, however archived plankton samples collected from surface waters around Scotland between 1960 and 2000 indicate a small, but significant, increase in the quantity of microplastics (Thompson et al. 2004).

There is evidence of marine litter on shorelines in all the OTs. With the exception of data collected in the Antarctic, South Pacific and the British Indian Ocean Territory, the information is limited to fairly anecdotal statements relating to voluntary beach cleans (Appendix II). However, it is clear that the majority of litter is made of plastics, with packaging and fishing-related items being particularly abundant. Recent reports from Henderson Island, a designated World Heritage Site in the South Pacific, indicate extremely high levels of contamination. Published estimates of over 37 million items of litter in a remote and uninhabited location like this indicate the potential for long-distance transport via ocean circulation (Lavers & Bond, 2017). Quantities of litter collected on shorelines in the British Antarctic Territories appear to be considerably lower than in the UK or other Overseas Territories, however detailed regional comparisons are not possible because of differences in sampling and recording methods. There are no data for sea surface contamination in the OTs, however, model estimates (van Sebille et al. 2015) predict high levels of contamination from small floating particles in the Pacific and Mediterranean, with much lower levels in The South Atlantic and Antarctic waters. Other OTs would be predicted to have intermediate levels of contamination. This pattern is loosely supported by the very limited empirical data available on microplastics concentrations in sediments (average number of pieces of microplastic per 250 ml sediment): British Indian Ocean Territory = 23 (Readman et al. 2013), South Georgia = 5 (Browne et al. 2011).

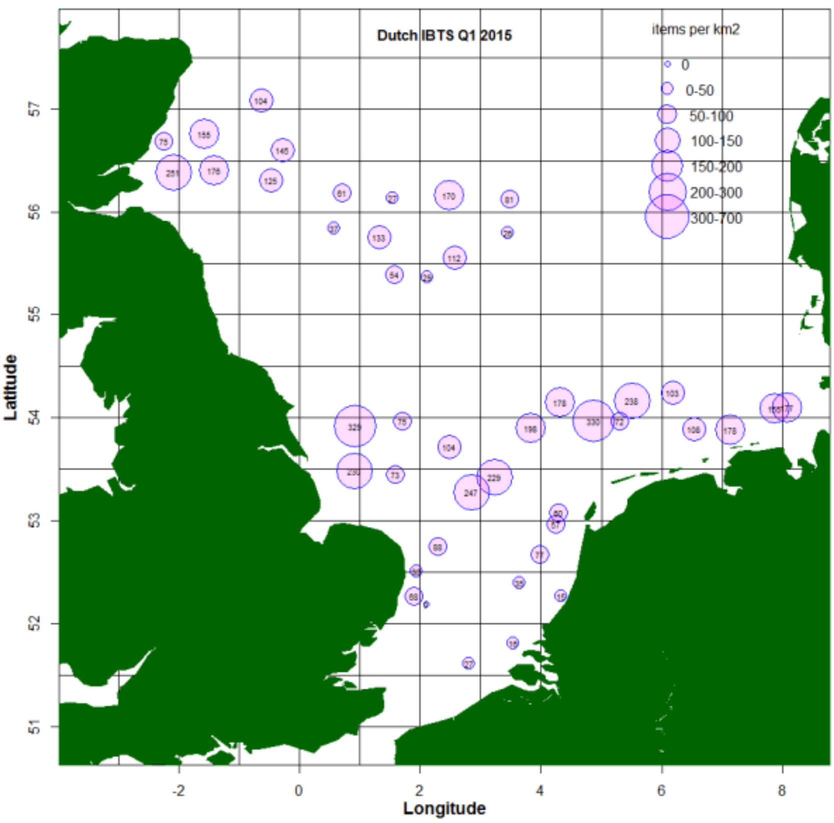

Figure 5. Density of litter on the seabed along the continental shelf collected from the Dutch International Bottom Trawl Survey (IBTS) in 2015. The numbers in the circle are the number of items per km^{-2}, areas without circles indicate a lack of sampling not an absence of litter. Source: van Hal (2015).

What Projections Exist for the Future?

There are considerable challenges in extrapolating from very limited empirical data to make predictions even about current patterns of spatial distribution and some of the best estimates available have uncertainty levels of over 100 fold (van Sebille et al. 2015). In addition, there is a lack of temporal data on which to base projections. Hence making reliable long-term future predictions is not feasible. Assuming business as usual, Jambeck et al. (2015) predict a three-fold increase in the amount of plastics in the ocean between 2015 and 2025 (Figure 6).

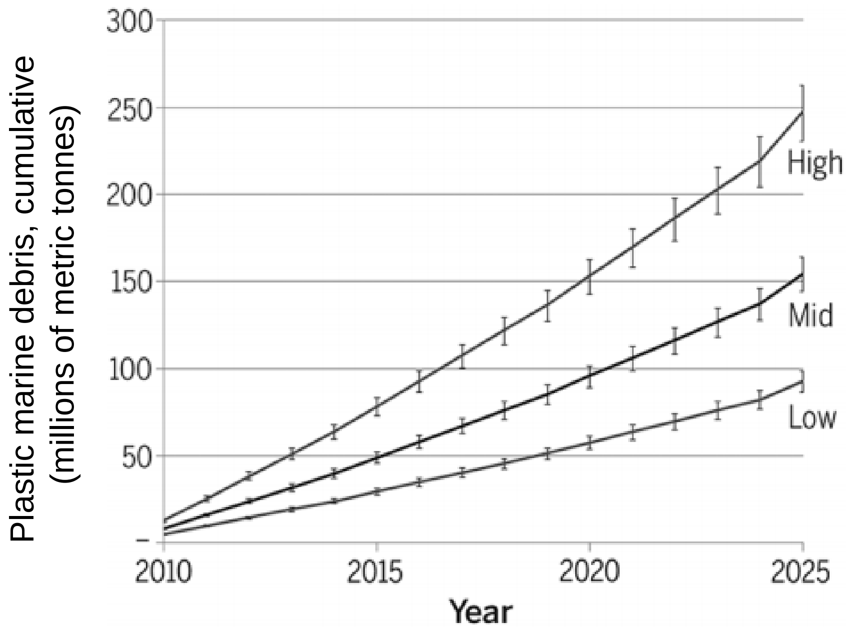

Figure 6. Estimated mass of plastic waste that enters the ocean because of inadequate waste management from populations living within 50 km of a coast in 192 countries, plotted as a cumulative sum from 2010 to 2025. Estimates reflect assumed conversion rates of mismanaged plastic waste to marine debris (high, 40 per cent; mid, 25 per cent; low, 15 per cent). See Jambeck et al. (2015) for details.

Attention is currently being directed within the EU (MSFD GES Technical Subgroup on Marine Litter 2011) to compare and harmonise monitoring protocols to allow greater inter-comparability among data, and this topic has recently been the focus of a workshop hosted by the Ministry of the Environment in Japan as part of G7. Harmonisation of monitoring will be a key step towards increasing the accuracy and inter-comparability of spatial and temporal estimates of plastic debris. However, it is important to acknowledge the heterogeneity of plastic litter and recognise that any particular method will only provide an index of the quantity of plastic within a sample. Given the practical limitations in sampling such a diverse form of contamination it may therefore be beneficial to link monitoring either to categories of litter where there is clear evidence of harm, or to assessing the efficacy of specific interventions, such as reductions in the quantity of plastic bags found in the environment as a consequence of the single-use bag tax or reductions in the abundance of plastic microbeads in sewage as a consequence of legislative measure to reduce the quantity of microbeads used in cosmetics. It is also essential to be explicit about the limitations of a given sampling strategy and the associated limitations of any extrapolations made in modelling studies.

Despite current uncertainties in estimating levels of contamination, it is clear is that plastics have only been mass produced since the1950s and therefore current levels of contamination reflect fairly rapid accumulation rates over just a few decades. The scale of the problem ahead is illustrated when one considers that on a global scale a similar quantity of plastics are likely to be produced in the next eight years as were produced in the whole of the 20th century (estimates updated to present day, after Thompson et al. 2009). At the same time it is important to recognise that the accumulation of plastics in the ocean is largely avoidable. By comparison with many other current environmental challenges the benefits resulting from the use of plastics are not *directly* linked to the emission of plastic debris to the environment or to degradation of the environment. Hence, in theory at least, it is possible for society to retain the benefits of plastic products and at the same time reduce the quantity of plastic litter entering the environment (Thompson 2015).

3. What is the Evidence for How these Changes will Affect the UK's Interests?

Contamination of the natural environment with plastics can have a range of negative effects on marine life, including species important in commercial fisheries, as well as on maritime industries and infrastructure. In addition, there is emerging evidence of effects on human well-being. Plastics are persistent contaminants, and so in the absence of actions to reduce inputs to the environment, all of these effects will continue to increase in frequency.

3.1 Marine Life

Plastic debris can affect marine organisms through entanglement and ingestion (Gall & Thompson 2015). Impacts vary according to the type and size of the debris and can occur at different levels of biological organisation in a wide variety of habitats (Browne et al. 2015; UNEP 2016; Werner et al. 2016).

Over 700 species of marine organism, including marine mammals, birds, fish and invertebrates, are known to encounter plastic debris. This can result in severe physical harm and death, or have more subtle sub-lethal effects on behaviour and ecological interactions; for example, by compromising an individual's ability to feed, escape from predators or migrate. It is anticipated that there is likely to be a range of sub-lethal effects yet to been recognised (Gall & Thompson 2015; Kuhn et al. 2015; Werner et al. 2016). Ingestion is widely reported and is particularly common for small fragments of debris, including a wide range of common post-consumer items such as bottle caps, balloons and sewage-related debris. By contrast abandoned, lost or discarded fishing gear is one of the main categories of debris resulting in entanglement and accounts for many reports of harm or death on a global scale (Macfadyen et al. 2009).

Numerous individuals from around 250 species are known to have become entangled in plastic debris. This includes over 50 species of marine mammals, over 100 species of sea birds, many species of fish and all seven species of marine turtles. Evidence of harm from entanglement is easier to observe, and hence report, than ingestion. This is because ingestion typically only becomes apparent when the carcass of an animal opens; either as a result of dissection or decomposition. In waters around the UK surveys indicate the incidence of entanglement ranges between 2–9 per cent for some populations of seabirds and marine mammals (Werner et al. 2016).

Around 300 species are known to ingest plastic litter in the environment. These range from small planktonic and benthic invertebrates to fish, birds and mammals (Gall & Thompson 2015; Kuhn et al. 2015; Werner et al. 2016). The potential for ingestion is greater with pieces in the microplastic size range (< 5mm). Quantities per individual are typically low, but contamination is widespread in some populations (see Appendix III). There is evidence from laboratory studies that microplastics can transfer between prey and predator (Watts et al. 2015) and this is therefore very likely in the environment when contaminated organisms are ingested whole.

Evidence of harm caused by ingestion of microplastics comes from laboratory experiments, mostly at concentrations higher than those in the environment. These indicate that ingestion can compromise the ability of planktonic organisms to feed (Cole et al. 2015) and the ability of marine worms (Wright et al. 2013) and fish (Cedervall et al. 2012) to gain energy from their food. There is also concern that microplastics might facilitate the transfer of organic and inorganic chemicals to biota (Holmes et al. 2012; Rochman & Browne 2013; Rochman et al. 2013). Current evidence suggests that microplastics are not likely to be a major vector in the transport of chemicals to organisms from seawater (Koelmans et al. 2013; Bakir et al. 2016. An additional pathway is the release of potentially harmful additives, such as flame retardants and plasticisers that were incorporated into plastic items during manufacture (Lithner et al. 2011; Rochman & Browne 2013). These additive chemicals can be present at high concentrations and there is evidence they can transfer to biota upon ingestion (Tanaka et al. 2013), but little is known about the potential for any associated toxicological effects.

While further research is needed to fully understand the environmental risks presented by microplastics it is considered that because these small particles are readily available to organisms via ingestion and can be mistaken for prey, that they are likely to present different types of hazards to larger items. For even smaller particles, in the nano size range, there is also the potential for uptake across cell membranes, but little is known about any associated impacts (Koelmans et al. 2016). On the balance of evidence available an expert working group recently concluded it was likely that such particles could exert sub-lethal effects on natural populations as a consequence of harmful physical and chemical effects (GESAMP 2016). There are also concerns about the potential for biological effects associated with the transfer of organisms between locations on plastic debris. For macroplastic debris this includes the transport of nonnative species of invertebrates (Gregory 2009), while microplastics have been implicated in the transfer of pathogenic microorganisms (Kirstein et al. 2016). However, the relative importance of plastics compared to other vectors, including natural floating debris such as logs, and transport via shipping, has yet to be established.

It is clear that encounters between plastic litter and organisms can negatively affect individuals and that a substantial proportion of some populations can be contaminated with plastics (Appendix III). For example over 40 per cent of sperm whales beached on North Sea coasts had marine litter including netting, ropes, foils and packaging material in their gastro-intestinal tract (Unger et al. 2016). An extensive data set for the Northern Fulmar indicated that over 95 per cent of individuals in some locations had plastic debris in their digestive tract (van Franeker et al. 2016; Figure 7). Scaling up evidence from impacts on individuals to population-level consequences is challenging since it is almost impossible to isolate the effects of plastic debris. For example, most species of marine turtles are red-listed by the International Union for Conservation of Nature as being (critically) endangered and frequent ingestion of plastics undoubtedly contributes to population decline; however, its level of contribution, as well as those of the other factors, cannot be isolated (Werner et al. 2016). Manipulative experiments have been used to isolate the effects of microplastics from other environmental stressors and here there is evidence of impacts, including effects on reproductive output, which could have associated population-level consequences (Sussarellu et al. 2016). However, many of the laboratory studies demonstrating effects from microplastics have used concentrations higher than those currently found in the environment (Lenz et al. 2016). While these experiments inform our understanding of thresholds in relation to future levels of contamination, they do not provide clear evidence of current environmental consequences.

Summarising across all of the evidence, the EU Marine Strategy Framework Directive (MSFD) expert group on marine litter recently concluded that plastics present a “large scale and serious threat to the welfare of marine animals” (Werner et al. 2016). Building on this it seems likely that there will be consequences at higher levels of biological organisation, including assemblages of organisms and the ecosystem services they provide. Teasing out such effects is challenging, but localised field experiments indicate even a single plastic carrier bag causes smothering which can alter the relative abundance of sediment-dwelling organisms as well as the ecosystem services they provide (Green et al. 2015). Recent experiments in microcosms also point to the potential for assemblage-level effects of contamination with microplastics (Green 2016; Green et al. 2017).

From a risk assessment perspective more work is needed to model the probability as well as the severity of encounters. This has recently been done for encounters between turtles and abandoned fishing nets in waters to the north of Australia (Wilcox et al. 2013). However, our wider ability to construct models of this type is limited, not only by a lack of understanding about some the specific types of harm caused by different types of plastic debris, but also a lack of detailed empirical data on the current distribution of this plastic. As a consequence, modelling future scenarios would currently be especially challenging.

Figure 7. Average abundance of plastics in a Fulmar stomach and scaled up to a human stomach. The average content of plastics in the stomach of Fulmars from the North Sea is shown to the left of the tweezers, currently just over 0.3 gm per stomach. To set this into context, to the right of the tweezers is the same average, but scaled to an organism of human body weight. This illustrates the relative quantity of litter but also provides a clearer visualisation of the litter types including considerable quantity of sheets, fragments, threads (top row), foams and industrial granules (bottom row). Source: Jan van Franeker – IMARES.

3.2 Maritime Industries

Contamination of the marine environment with plastic debris can have negative effects on tourism, fisheries, aquaculture and navigation (Figure 8). However, evaluating individual socio-economic costs of litter is challenging because of limited understanding about impacts and as a consequence of the variety of approaches that can be used to place economic values on the natural environment.

3.3 Fishing & Shipping

Plastic litter can impact on fisheries reducing and damaging catches as well as damaging vessels. The types of litter that are most frequently caught in fishing gear are ropes and other plastics, with 90 per cent of respondents in a survey among Scottish trawlers finding these items (Figures 8 and 9; Mouat et al. 2010), with an average cost to each vessel in the region of £16,000 per year. However, the exact economic costs depend on the quality of the fishing at the time and location of the incident. The issue of propellers and other structures becoming tangled in plastic debris extends to other maritime industries including aquaculture. Total costs to the aquaculture sector are currently relatively low, because the frequency of encounter is limited (Mouat et al. 2010).

The effects of plastic litter are not limited to fishing vessels: there are numerous life-boat call-outs related to entanglement of propellers, the seriousness of which was highlighted by the sinking of the Ferry M/V Soe-Hae in 1993 which was, in part, caused by rope around the propellers, and resulted in 292 deaths (Cho 2005). Clearly, the frequency of these negative impacts will increase in relation to increasing levels of contamination.

As well as effects on the operation of fishing vessels there are concerns about contamination of the fish stock; with 49 commercially important species including sardines, herring, hake, whiting and red mullet being known to ingest microplastics (Appendix III; Kuhn et al. 2015; GESAMP 2016). For example, a study in South West England showed that of 504 fish, from 10 species, over one-third had microplastics in their digestive tract (Lusher et al. 2013). Similar results were obtained in the southern North Sea (Foekema et al. 2013). Shellfish including mussels, clams, oysters and scallops also ingest microplastics (Kuhn et al. 2015). For example, in the Firth of Clyde over 80 per cent of the commercially important *Nephrops norvegicus* (Norway lobster, Dublin Bay prawn or sometimes scampi) contained microplastics (Murray & Cowie 2011). Despite this widespread occurrence, the quantity of plastics in seafood is currently quite low, with a contaminated individual typically containing one or two items of plastic. Hence it seems unlikely that current levels of microplastic would be harmful to humans. However, there is concern in the fishing and aquaculture industry that even small quantities of plastic might be perceived negatively by consumers and affect marketability (GESAMP 2016). It is also

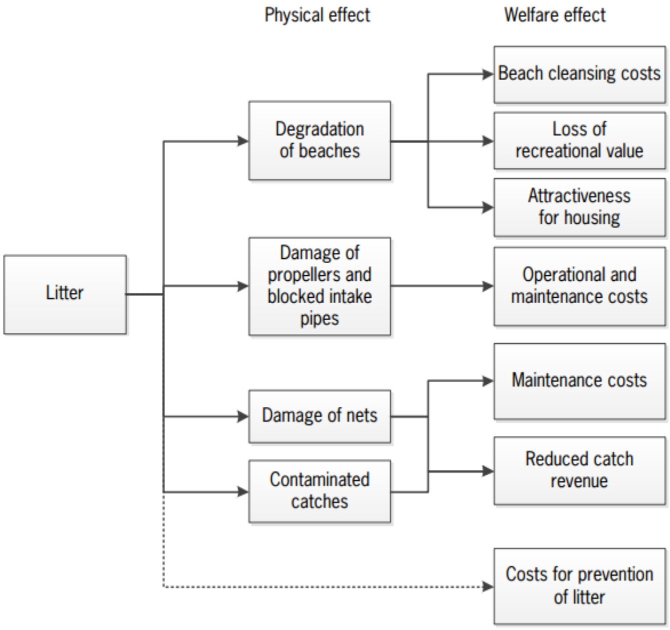

Figure 8. Impacts of beach and marine litter on socio-economic activities

Source: Reinhard et al. (2012)

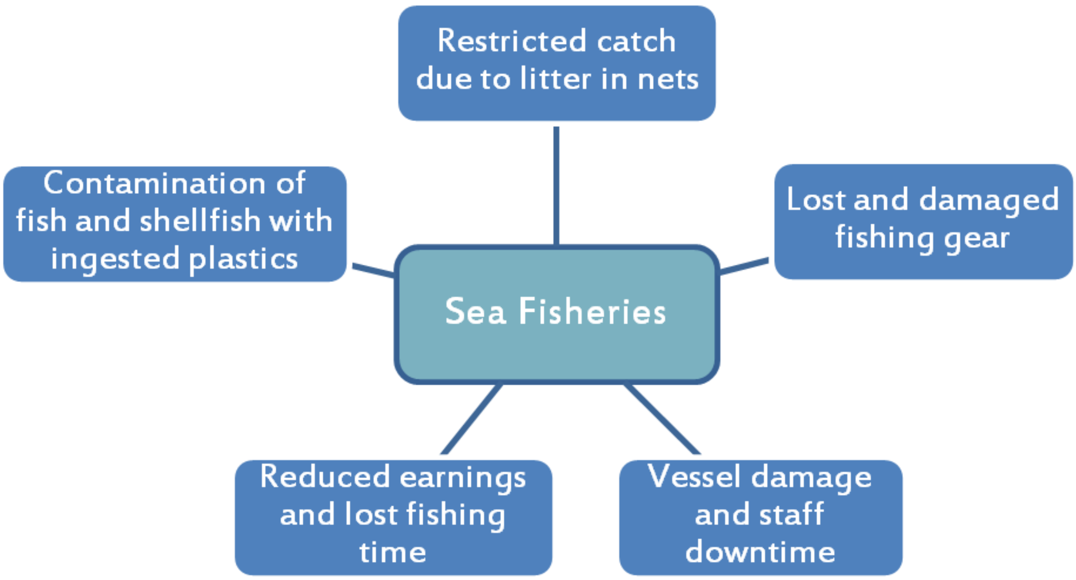

Figure 9. Potential impacts of marine litter on fisheries

Adapted from Mouat et al. (2010)

important to recognise that even if we were able to reduce inputs of macroplastics to the ocean the quantity of microplastics in the ocean will increase over the next few decades because of the fragmentation of the macroplastic debris that is already present (Thompson 2015). The probability of impacts associated with microplastic contamination will, therefore, also be expected to increase.

3.4 Maritime Infrastructure

Over 71 per cent of harbours and marinas surveyed in the UK reported that their users had experienced entangled propellers, entangled anchors, entangled rudders and blocked intake pipes and valves. The total annual cost of removing litter from 34 UK harbours was estimated at approximately £236,000; based on this, it was estimated that marine litter costs the ports and harbour industry in the UK approximately £2.1 million each year (Mouat et al. 2010).

3.5 Tourism

A recent EU-wide survey demonstrated that over 70 per cent of visitors noticed litter on either most or every visit to the coast (Hartley et al. 2013). Visitors regarded litter as very annoying and it influenced the locations they chose to visit (Brouwer et al. 2015). In the UK during 2010, around 40 per cent of local authorities undertook beach cleaning with annual costs in the region of £15.5 million (Mouat et al. 2010). However it must be recognised that in many locations the true cost is subsidised by extensive voluntary beach cleaning.

3.6 Health & Well-being

The public are concerned about the accumulation of both macroplastics and microplastics in the environment and regard litter as an important current environmental problem (Hartley et al. 2013; Appendix IV). Litter on beaches can cause physical injuries (Werner et al. 2016), but these incidents most frequently relate to glass and metal objects rather than plastic. However, there is evidence that even relatively small amounts of macroplastic litter can have a negative effect on what psychologists would describe as the *restorative* value, from the perspective of human well-being, of a visit to the coast (Wyles et al. 2015).

It has been suggested in some media reports that consumption of fin-fish and shellfish that are contaminated with microplastics might present a threat to human health. However, the quantities of microplastics in seafood are typically low. In addition, studies of contaminated fish describe microplastics in the gut and this is typically removed before consumption. Similarly with shellfish there is typically a depuration period prior to consumption. For organisms eaten whole, including the gut, estimates for high annual consumption of mussels indicated potential for transfer of 11,000 microplastic particles to an individual consumer (Van Cauwenberghe & Janssen 2014). Even in this fairly atypical scenario there is no evidence to indicate that microplastic would be harmful.

One recent study modelled the potential for transfer of harmful chemicals to marine organisms by several types of microplastics and then considered the consequences if these organisms were subsequently eaten by humans. The simulations predicted that microplastics were not likely to be an important factor in the transport of chemicals from seawater (Bakir et al. 2016). However, more work will be needed to establish the potential for transfer of chemical additives, incorporated in plastic items at the time of manufacture, and which can be present at high concentrations (Bakir et al. 2016). For example a recent study in Korea demonstrated that potentially harmful flame retardants could be released from buoys used in an aquaculture facility, leading to elevated concentrations of flame retardants in the surrounding environment (Al-Odaini et al. 2015). More work is needed to establish the potential health risks from microplastics. This would require an assessment of dietary exposure to microplastics via a range of foods (GESAMP 2016) as well as work to establish the potential consequences of such ingestion.

A final concern from a human health perspective is that plastic debris can support diverse microbial communities that are distinct from those found in seawater or on other floating objects. Hence the colonisation, survival and transport of pathogens on polymers presents a potential risk to human health, but further investigation is needed to establish the importance of this (Keswani et al. 2016; Kirstein et al. 2016).

4. Evidence to Inform Policy Responses

There are a range of policy measures and international conventions relating to marine litter (Appendix V), however the continuing projected increases suggest that additional measures may be needed. In some cases there are difficulties associated with enforcement, for example the regulation of dumping at sea (MARPOL Annex 5) is extremely difficult to enforce. It is also essential to better understand the relative importance of the various sources of litter and to assess how these vary regionally, for example comparing litter and waste management in the UK and the OTs. It should also be recognised that contamination of the ocean by plastic is a global problem. Although there is evidence that considerable quantities of litter remain relatively close to their point of origin to the ocean, it is also clear that litter does not respect international boundaries and that it can travel considerable distances. So, while it is important to minimise any direct inputs of plastic litter to the ocean from the UK and the OTs, it is also clear that effective long-term change can only be achieved by working internationally.

There is a reasonably extensive evidence base relating to the harm caused by marine litter (Section 3). There are gaps in our knowledge requiring further research to establish specific evidence; however there is general consensus that marine litter is problematic and that action is required to reduce the quantity of plastics escaping to the oceans. Hence, as well as further defining the scale of the problem it is important to address knowledge gaps relating to solutions such as research focused at changing behaviour and practices. Plastics are very useful materials that bring an extensive range of societal benefits. Plastic production has increased considerably over the last few decades; the carbon used to make this plastic is mainly derived from oil and currently accounts for around 4 per cent of world oil production . However, extensive use of plastics *per se* is not the sole cause of the problem, it is the decisions made about how to produce, use and dispose of plastic items that result in waste and litter. Around 40 per cent of production is of single-use items and these items account for a large proportion of waste and litter. Most plastics are inherently recyclable, yet many single-use items are not compatible with recycling. A key challenge therefore is to ensure end-of-life disposal is appropriately considered at the design stage.

Historically, most measures to reduce marine litter (Appendix V) have focused on end-of-pipe solutions. Marine litter is a problem in the sea, but it mostly originates on the land; long-term, sustainable solutions should therefore consider the whole supply chain.

Recycling has several benefits: if more end-of-life material can be recycled it not only reduces the quantity of waste that needs to be managed via other approaches such as landfill, or that has the potential to enter the environment as litter, it also reduces the requirement for fossil oil and gas to manufacture new plastics (Koelmans et al. 2014; Thompson 2015). There is a lack of understanding about the behaviours that lead to littering as well as those that lead to engagement in recycling (Pahl & Wyles 2017).

Some actions could inadvertently confuse or compromise the responses outlined above. For example, the use of 'bio-based' carbon obtained from plants grown in agriculture is seen as a sustainable alternative to fossil carbon, but on its own this will not reduce the generation of waste or the accumulation of litter. In addition, designing plastic products so that they degrade or disintegrate more rapidly may, over time, reduce the accumulation of large items of debris, however, such products may compromise the potential for product re-use, contaminate recycling, and accelerate the production of microplastic fragments (Thompson et al. 2009).

The benefits of citizen-focused activities such as beach cleaning are well recognised from an educational as well as a litter-removal perspective (Nelms et al. 2017). However, there are concerns about the efficacy and viability of large-scale mechanical clean-up operations at sea. This is because current rates of entry for litter to the marine environment far exceed the potential for removal by clean-up. This suggests that priority policy focused on preventing litter entering the oceans in the first place will be more effective.

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Appendices

Appendix I

Twenty most common items of litter recorded during Marine Conservation Society Beach cleans 2005–2014. Fragments of plastics cannot directly be assigned to categories of usage type, but it is reasonable to assume that they arise from the fragmentation of the other items listed that are still sufficiently intact to be identifiable (caps, packets, bottles, etc.), (see Nelms et al. 2017).

Item category	Proportion
Plastic fragments (large; > 2.5 cm)	0.13
Plastic fragments (small; < 2.5 cm)	0.10
Plastic caps	0.07
Polystyrene (small; < 50 cm)	0.07
Crisp packets	0.06
Fishing net (small; < 50 cm)	0.05
Plastic string	0.05
Plastic drinks bottles	0.04
Cotton buds	0.03
Fishing line	0.03
Cigarette stubs	0.03
Plastic cutlery	0.02
Glass fragments	0.02
Cloth pieces	0.02
Plastic bags	0.02
Polystyrene foam	0.02
Metal Drinks can	0.02
Plastic rope	0.01
Fishing net (large; > 50 cm)	0.01
Wood pieces	0.01

Appendix II

Sources of information providing recent accounts of marine litter in British Overseas Territories

Bermuda	Ocean Conservancy, 30th Coastal Clean-up data http://www.oceanconservancy.org/our-work/marine-debris/2016-data-release/2016-data-release-1.pdf
British Antarctic Territory	Waluda C. (2016) Marine Debris and Entanglements at Bird Island and King Edward Point, South Georgia, Signy Island, South Orkneys and Goudier Island, Antarctic Peninsula 2015–2016, Report for Commission for the Conservation of Antarctic Marine Living Resources. Available from C. Waluda, British Antarctic Survey.
British Indian Ocean Territory	Readman, J. W., DeLuna, F., Ebinghaus, R., Guzman, A.-N., Price, A. R. G., Readman, E. W., Sheppard, A. L. S., Sleight, V. A., Sturm, R., Thompson, R. C., Tonkin, A., Hendrik, W., Wright, R. J. & Sheppard, C. R. C. 2013 Contaminants, Pollution and Potential Anthropogenic Impacts in Chagos/BIOT. In *Coral Reefs of the United Kingdom Overseas Territories*, vol. 4 (ed. R. C. Sheppard), 323. Heidelberg: Springer.
British Virgin Islands	Ocean Conservancy, 30th Coastal Clean-up data http://www.oceanconservancy.org/our-work/marine-debris/2016-data-release/2016-data-release-1.pdf
Cayman Islands	Ocean Conservancy, 30th Coastal Clean-up data http://www.oceanconservancy.org/our-work/marine-debris/2016-data-release/2016-data-release-1.pdf
Falklands Islands	http://www.falklandsconservation.com/news/221-marine-debris-falkland-islands
Gibraltar	https://www.gibraltar.gov.gi/new/sites/default/files/HMGoG_Documents/MSFD_Marine_Monitoring_Programme.pdf
Monserrat	https://www.themontserratreporter.com/bunkum-bay-beach-clean-up-yields-bumper-garbage-haul
South Georgia and the South Sandwich Islands	Browne, M. A., Crump, P., Niven, S. J., Teuten, E., Tonkin, A., Galloway, T. & Thompson, R. 2011 Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. *Environmental Science & Technology* 45, 9175–9179. Waluda C. (2016) Marine Debris and Entanglements at Bird Island and King Edward Point, South Georgia, Signy Island, South Orkneys and Goudier Island, Antarctic Peninsula 2015–2016, Report for Commission for the Conservation of Antarctic Marine Living Resources. Available from C. Waluda, British Antarctic Survey.

Appendix III

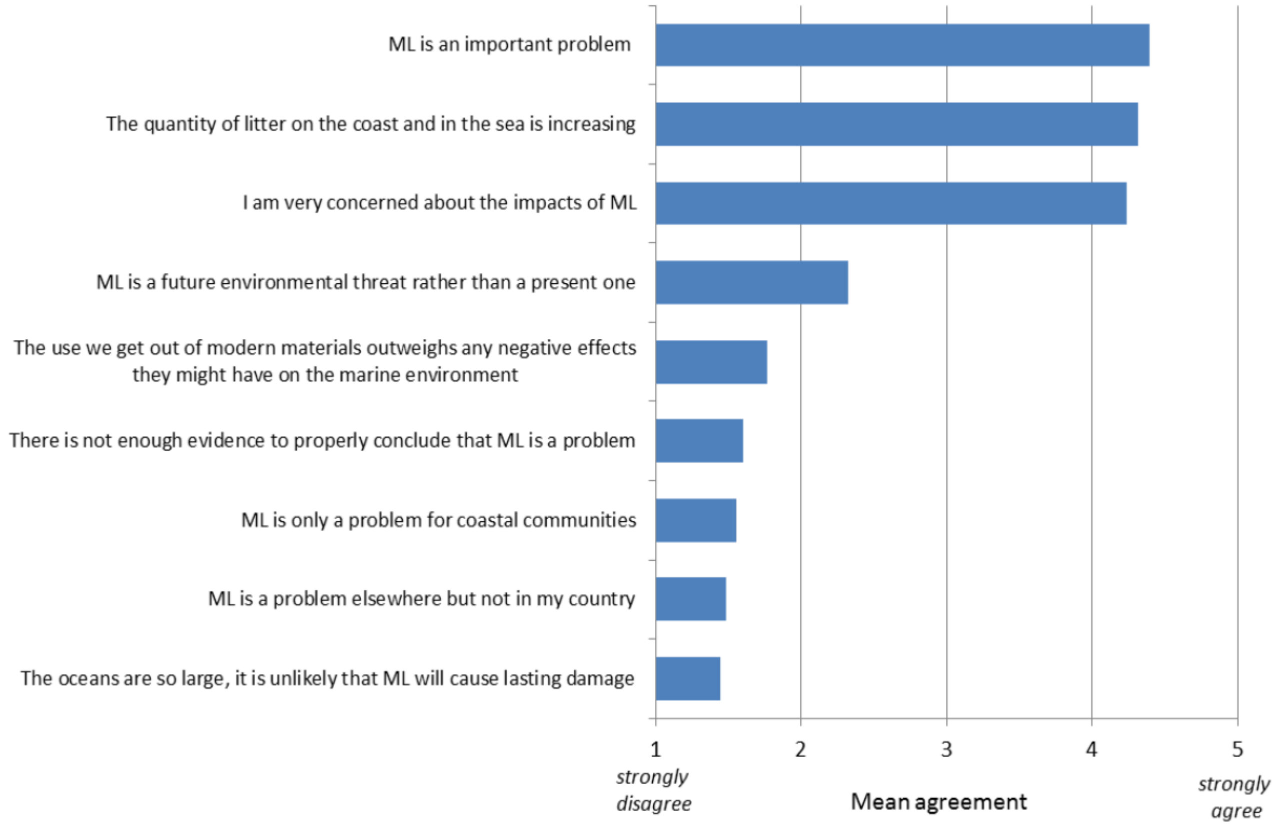
Frequency of plastic ingestion for selected species populations. Note the first six rows describe species of commercial importance in the UK (Werner et al. 2016 – where full details of all references are given).

Species	Size of sample	% individuals with ingestion	Geography	Sources
Norway Lobster ***Nephrops norvegicus***	120	83%	Clyde Estuary, Scotland	Murray & Cowie 2011
Atlantic Herring ***Clupea harengus***	566	2%	North Sea	Foekema et al., 2013
Whiting ***Merlangius merlangus***	105	6%	North Sea	Foekema et al., 2013
Horse Mackerel ***Trachurus trachurus***	100	1%	North Sea	Foekema et al., 2013
Haddock ***Melanogrammus aeglefinus***	97	6%	North Sea	Foekema et al., 2013
Atlantic cod ***Gadus morhua***	80	13%	North Sea	Foekema et al., 2013
Northern Fulmar ***Fulmarus glacialis***	1295	95%	North Atlantic	van Franeker et al., 2011
Common Murre ***Uria aalge***	220	2.3%	Wales, UK	Weir et al., 1997
Razorbill ***Alca torda***	81	1%	Wales, UK	Weir et al., 1997
Red-throated Loon ***Gavia stellate***	19	5%	Wales, UK	Weir et al., 1997
Black-headed Gull ***Larus ridibundus***	18	11%	Germany	Schwemmer et al., 2012
Cory's Shearwater ***Calonectris borealis***	49	96%	Mediterranean Sea	Codina-Garcia et al., 2013

Harbour Seal ***Phoca vitulina***	107	11.2%	North Sea	Bravo Rebolledo et al., 2013
Harbour Porpoise ***Phocoena phocoena***	42	11.9%	Black Sea	Tonay et al., 2007
True's Beaked Whale ***Mesoplodon mirus***	3	66.6%	Ireland	Lusher et al., 2015
Sperm Whale ***Physetermacrocephalus***	22	40.9 %	North Sea	Unger et al., 2016
Loggerhead Turtle ***Caretta caretta***	121	14%	Mediterranean Sea, Sardinia	Camedda et al., 2014
	31	71%	Mediterranean Sea, Italy	Campani et al., 2013
	54	79.6%	Mediterranean Sea, Spain	Tomás et al., 2002
	2214	40.4%	Mediterranean NW	Darmon et al., 2014
Marine Turtles (all species)	153	35.4%	NE Atlantic	Darmon et al., 2014

Appendix IV

Risk perceptions and concern about the problem of marine litter (ML), 1-5 scale: strongly disagree – strongly agree (Hartley et al. 2013).



Appendix V

Policies and conventions related to marine litter

- United Nations Convention on the Law of the Sea (UNCLOS) and General Assembly (GA) Resolutions: sets out the legal framework within which all activities in the oceans and seas must be carried out. The Regional Seas programme aims to address the accelerating degradation of the world's oceans and coastal areas through the sustainable management and use of the marine and coastal environment, by engaging neighbouring countries in comprehensive and specific actions to protect their shared marine environment.
- Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (UNEP, Regional Seas programme): an intergovernmental programme addressing inter-linkages between freshwater and the coastal environment.
- International Convention for the Prevention of Pollution from Ships (MARPOL 73/78 and Annex V).
- London Convention 1972, Convention on the Prevention of Maritime Pollution by Dumping of Wastes and Other Matter, and 1996 Protocol Thereto.
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.
- Convention on Biological Diversity, with the Jakarta Mandate: Ministerial Statement on the Implementation of the Convention on Biological Diversity.
- FAO Code of Conduct for Responsible Fisheries: the Code provides a framework for national and international efforts to ensure sustainable exploitation of aquatic living resources in harmony with the environment.
- Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP): GESAMP is an advisory body that advises the United Nations (UN) system on the scientific aspects of marine environmental protection.
- OSPAR Convention: a mechanism by which 15 Governments of the western coasts and catchment areas of Europe, together with the European Community, cooperate to protect the marine environment of the North-East Atlantic. OSPAR covers five subregions: Arctic, North Sea, Celtic Seas, Bay of Biscay and Iberian Coast, and Wider Atlantic. Activities on marine litter are covered by the Biodiversity Committee (BDC), the Working Group on Environmental Impact of Human Activities (EIHA) and the Intersessional Correspondence Group on Marine Litter (ICG-ML).

- The EU Marine Strategy Framework (Directive 2008/56/EC) (MSFD). Descriptor 10: properties and quantities of marine litter do not cause harm to the coastal and marine environment.
- The EU Directive on the landfill of waste (Directive1999/31/EC): to prevent or reduce negative effects on the environment from the landfilling of waste, including the pollution of surface water. Applicable to litter from landfills entering the seas and becoming marine litter.
- The EU Directive on port reception facilities for ship-generated waste and cargo residues (Directive 2000/59/EC, December 2002) focuses on ship operations in Community ports and addresses in detail the legal, financial and practical responsibilities of the different operators involved in delivery of waste and residues in ports.
- The EU Directive on packaging and packaging waste (Directive 2004/12/EC) to encourage packaging re-use and recycling.
- The EU Directive on the conservation of natural habitats and of wild fauna and flora (DIRECTIVE 92/43/EEC) of 21 May 1992 to promote the maintenance of biodiversity by requiring Member States to take measures to maintain or restore natural habitats and wild species at a favourable conservation status, introducing robust protection for those habitats and species of European importance.
- The Water Framework Directive (Directive 2000/60/EC) for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater**.**
- The EU Directive concerning the management of bathing water quality (Directive 2006/7/EC).
- The Single Use Carrier Bag Charge (England) Order 2015, No. 776.
- Proposals to ban the use of plastic microbeads in cosmetics and personal care products in the UK and call for evidence on other sources of microplastics entering the marine environment. December 2016.

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