Marine Litter

Vital Graphics

UNEP

GRID ARENDAL

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Vital Graphics

Contents

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Foreword

Every year, the sum of humanity's knowledge increases exponentially. And as we learn more, we also learn there is much we still don't know. Plastic litter in our oceans is one area where we need to learn more, and we need to learn it quickly. That's one of the main messages in *Marine Litter Vital Graphics*. Another important message is that we already know enough to take action.

It sounds like a contradiction, but it's not. As this report explains, we need to act now if we want to avoid living in a sea of plastic by mid-century – even if we don't know everything about what it's doing to the health of people or of the environment.

Produced by UNEP and GRID-Arendal, this report shows that we have to take a hard look at how we produce and use plastics.

The first plastics hit the market around 1950. At that time there were 2.5 billion people on Earth and the global production of plastic was 1.5 million tonnes. Today there are more than 7 billion people and plastic production exceeds 300 million tonnes annually. If the trend continues, another 33 billion tonnes of plastic will have accumulated around the planet by 2050.

It's all about consumption. As the global standard of living has grown, the amount of plastic produced, used and simply thrown away has skyrocketed – and a vast quantity makes its way to the ocean.

The presence of marine litter in birds, turtles and mammals is well documented. A recent comprehensive review revealed marine litter in 100% of marine turtles, 59% of whales, 36% of seals and 40% of seabirds.

But large marine creatures swallowing or getting caught in rubbish are only part of the problem. Organisms at every level, living on the seabed and in the water column, can be affected. Apart from the physical risk from plastic there is also concern they are threatened by the ingestion of hazardous chemicals in the plastic or absorbed on its surface. The ability of plastic particles in the ocean to attract organic chemicals that don't dissolve, including many toxic substances, has led to a growing number of studies looking at plastics as a source of toxic chemicals in marine organisms. What happens to the health of people who eat food from the sea is another important question.

In fact, the report points to the need for more research in every area. It states that our knowledge about what happens to plastics in the marine environment should be seen as only the tip of the iceberg. Much more is unknown than known.

The good news is that while a lot of research needs to be done there is a lot we can do to change our consumption and production patterns to prevent increasing amounts of plastic waste from getting into the marine environment.

"Upstream" governance actions can help reduce the amount of plastic. Recycling is one example, but that captures only a small portion of waste plastic. Other actions include prohibitions and creating financial disincentives to the manufacture and use of plastic materials.

Besides improved governance at all levels, long-term solutions should focus on behavioural and system changes such as encouraging more sustainable production and consumption patterns.

Upstream prevention is preferable to downstream removal. Or as one of the report chapters says, it's better (and cheaper) to be tidy than to have to tidy up.

Knowledge about the effects of plastic in the marine environment is growing rapidly. We hope that this report will provide much needed impetus to action.

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What is marine litter and why it is of concern

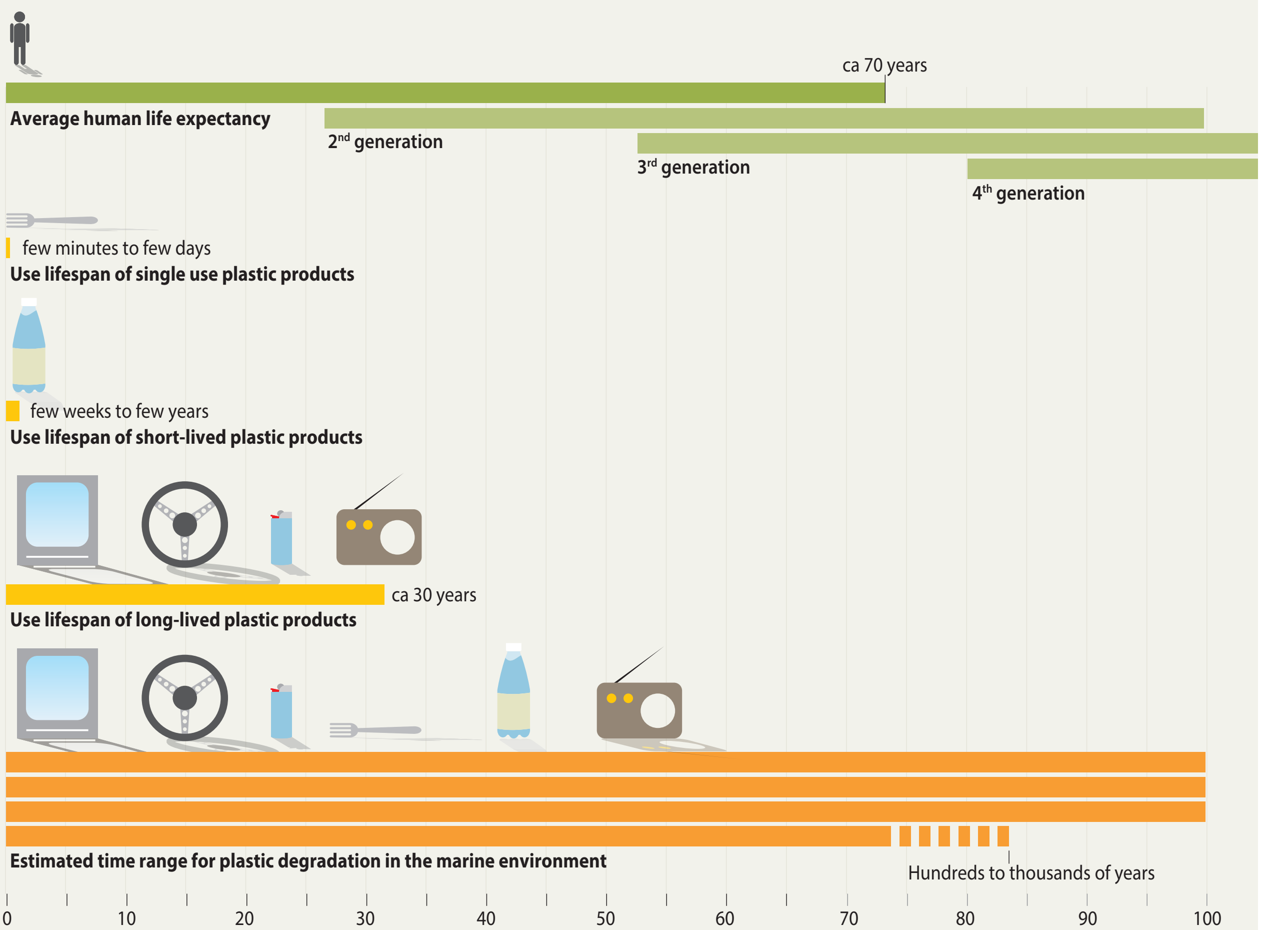
Marine litter (or debris)* is waste created by humans that has been discharged into the coastal or marine environment. It is defined as "any anthropogenic, manufactured, or processed solid material (regardless of size) discarded, disposed of, or abandoned in the environment, including all materials discarded into the sea, on the shore, or brought indirectly to the sea by rivers, sewage, storm water, waves, or winds" (UNEP and NOAA, 2012).

Just as human activities are varied and widespread, so are the sources of litter. The sources may be located directly at sea, on the coast or further inland. Litter can be transported over long distances and into all marine habitats – from the surf zone all the way to remote mid-oceanic gyres and the deep sea floor. Like other pollutants, marine litter affects habitats, ecological function and the health of organisms of the ecosystems where it accumulates.

Any human-made object that does not naturally degrade within days or months can potentially become marine litter if it is not properly managed. Common litter items are made of paper, wood, textiles, metal, glass, ceramics, rubber and plastic discarded by humans (UNEP, 2005).

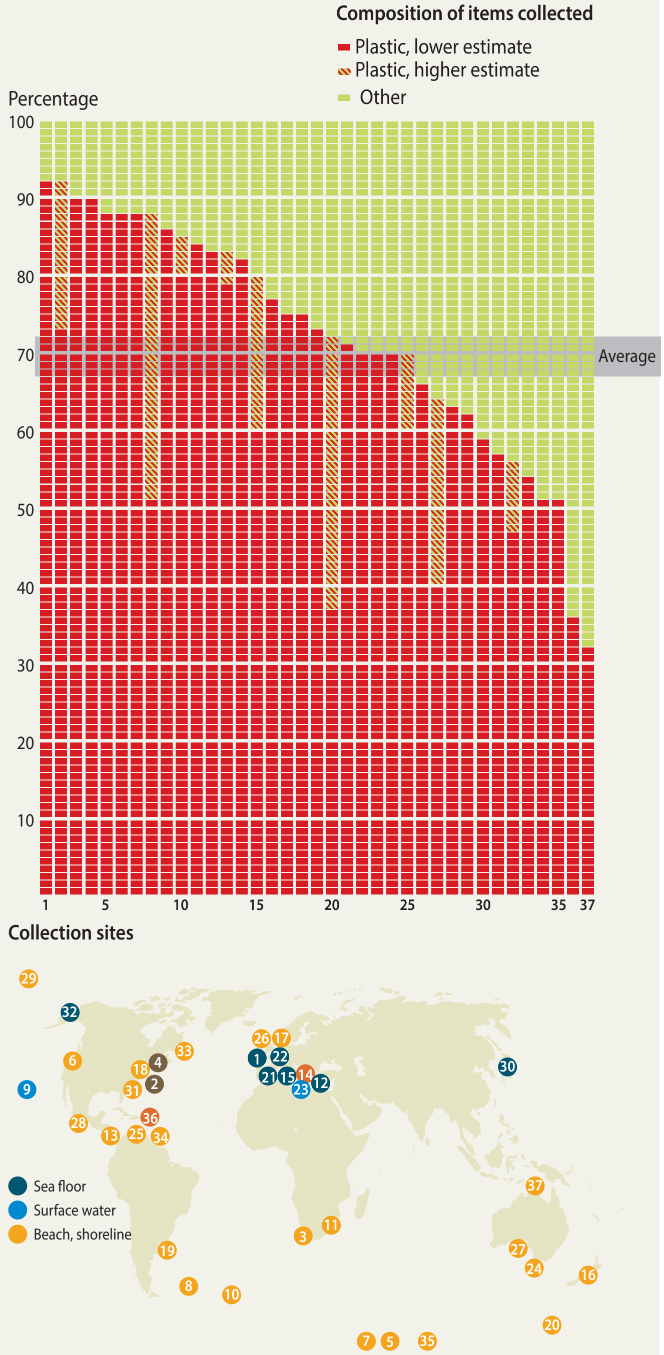
*The terms litter and debris are considered to have the same meaning in this report and are used interchangeably throughout.

Are most of the plastics produced still around?



Source: Barnes, D. K., et al., Accumulation and fragmentation of plastic debris in global environments, Biological Sciences

Mostly plastic



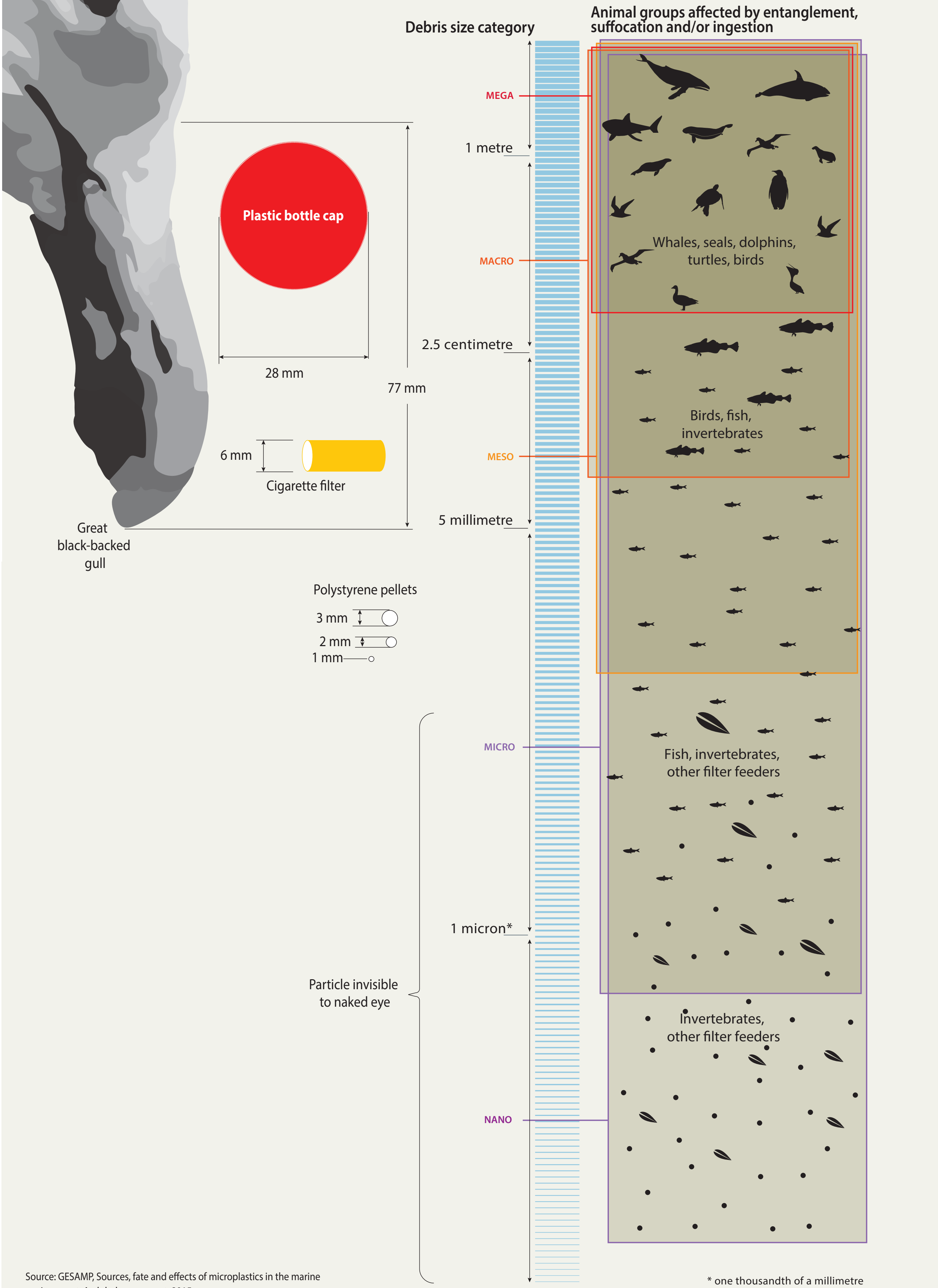
1. Bay of Biscay
2. North Atlantic harbours (4 sites)
3. South African beaches (50 sites)
4. Cape Cod
5. Sub-Antarctic Islands (9 sites)
6. National Parks in USA
7. Prince Edward Island
8. Bird Island
9. North Pacific Ocean
10. Gough Island
11. Transkei, South Africa
12. Gulfs in W. Greece (2 sites)
13. Caribbean coast of Panama
14. Mediterranean beaches (5 sites)
15. NW Mediterranean sea bed (avg.)
16. New Zealand Beach
17. South German Bight
18. Island Beach State Park, New Jersey
19. Argentina
20. Macquire Island
21. French Mediterranean Coast (avg.)
22. European coast (avg.)
23. Mediterranean Sea
24. Tasmania (88 sites)
25. Curaçao
26. South Wales
27. South Australia
28. Mexico
29. International Coastal Cleanups, 1992 (avg.)
30. Tokyo Bay
31. Georgia
32. Kodiak Island
33. Halifax Harbour
34. St. Lucia
35. Heard Island
36. Dominica
37. Fog Bay, Northern Australia

Source: Derraik, J., G., B., The pollution of the marine environment by plastic debris: a review, 2002

Between 60 and 90 per cent – sometimes as much as 100 per cent – of the litter that accumulates on shorelines, the sea surface and the sea floor is made up of one or a combination of different plastic polymers. The most common items, constituting over 80 per cent of the litter stranded on beaches (Andrady, 2015) are cigarette butts, bags, remains of fishing gear, and food and beverage containers. Likewise, 90 per cent of the litter collected from sea floor trawls is made up of plastic (Derraik, 2002 and Galgani et al., 2015).

Plastics have only been mass-produced for around 60 years and therefore it is impossible to know with certainty how long they last in the marine environment. Most types of plastic are not biodegradable (Andrady 1994). In fact, they are extremely durable. This means the majority of polymers manufactured today will persist for decades and probably for centuries, if not millennia. So-called degradable plastics may persist for a long time because their degradation depends on physical factors, such as exposure to light, oxygen and temperature (Swift & Wiles 2004). Biodegradable plastics also decompose through the mediation of certain micro-organisms. Plastics labelled as biodegradable, designed to undergo certain degrees of degradation in landfills or in terrestrial environments, may still persist for long periods under marine conditions (Kyrikou & Briassoulis, 2007; UNEP, 2015). Full degradation of a plastic item implies complete breakdown and decomposition into water, carbon dioxide, methane and other non-synthetic molecules. For the large majority of plastic items, even if they disintegrate by breaking down into smaller and smaller plastic debris under the influence of weathering, the polymer itself may not necessarily fully degrade into natural chemical compounds or chemical elements under marine conditions (Hopewell et al., 2009).

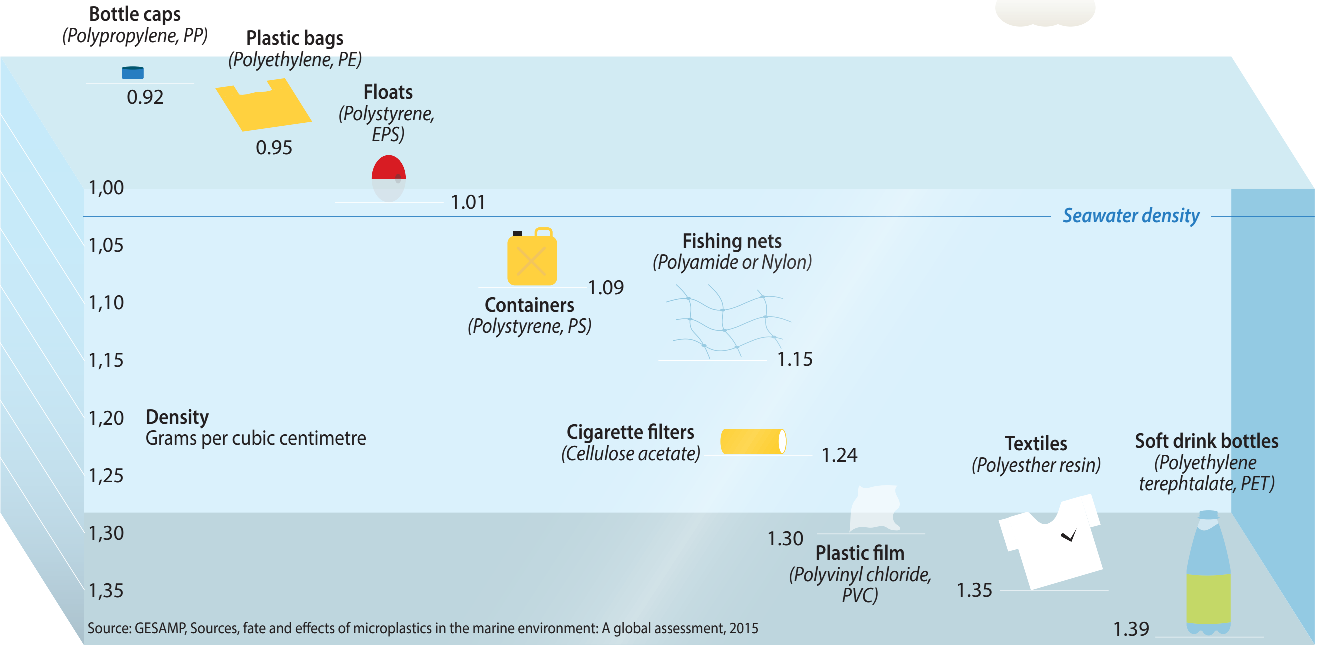
Size does matter



Source: GESAMP, Sources, fate and effects of microplastics in the marine environment: A global assessment, 2015

* one thousandth of a millimetre

Which plastics float and which sink in seawater?



In addition to polymers, additives such as flame retardants (e.g. polybrominated diphenyl ethers), and plasticisers (e.g. phthalates) are also mixed into synthetic materials to increase their flexibility, transparency, durability, and longevity. Some of these substances, present in most plastic objects found in the marine environment, are known to be toxic to marine organisms and to humans (Rochman et al., 2015).

The plastic used in the manufacture of an object depends on its intended use. The type of plastic will determine the ease with which an object can be recycled. Some plastics cannot be recycled, which means they enter the waste management system. If they make it into the marine environment, plastics that are less dense than sea water will float at the surface. Floating objects can be readily transported by wind, waves and surface currents and become widely dispersed across the ocean. Plastics that are denser than sea water will sink to the sea floor and accumulate or be redistributed, along with other sedimentary particles, through bottom sedimentary processes.

Marine litter comes in all sizes. Large objects may be tens of metres in length, such as pieces of wrecked vessels, lost fishing nets and lost cargo containers. Moderate sized objects less than one metre long might include plastic bags, soda bottles or milk containers. Small spheres of expanded polystyrene are on the scale of millimetres. Micrometre-sized plastic beads are present in cosmetic products and synthetic cloth fibres or are derived from fragments broken down from larger plastic items.

There has recently been a noticeable increase in concern about the implications of pollution by small sized debris, especially where made up of plastic. The term "microplastic" has been introduced to describe small plastic debris commonly less than 5 mm in diameter. The concern about microplastic pollution is due to its ubiquitous presence in the marine environment. Yet it is difficult to assess its quantity because of the small size of the particles and the fact that little is known about the chemical reactions and the extent of its incorporation into the trophic chain. Investigations are also being conducted into the implications of organisms' exposure to and intake of plastic nanoparticles, particles smaller than 1 micron. With such limited knowledge of the ultimate ecological effects of microplastics and nanoplastics, there are concerns over their potential impacts at the level of ecosystems.

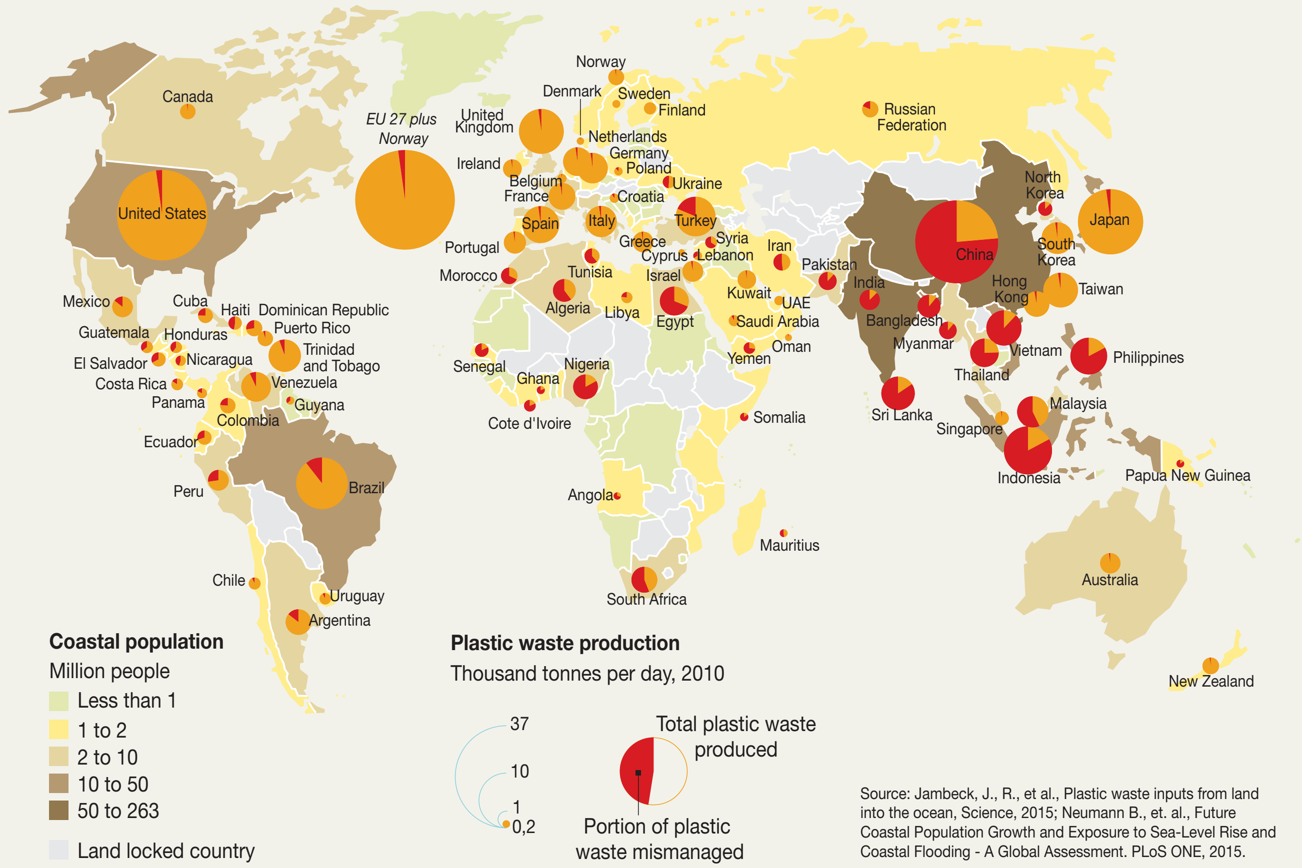
Modern times, marine litter

Today´s deterioration of the global environment is closely linked to unsustainable patterns of consumption and production. The exponential increase in production and consumption over the last 50 years has seen a rapid transformation of the relationship between humans and the natural world – more so than in any other period in our history – with escalating use of natural resources leading to environmental degradation (UNEP, 2015). The increase in production and consumption is across all sectors and generates a vast amount of waste, much of it contributing to marine litter. This includes waste streams such as wood, textiles, metal, glass, ceramics, rubber and above all, plastic.

The rapid rise in the use of oil and gas during the last half century has been accompanied by the development of a range of petroleum products, some of which, like petrochemicals, have other important applications beyond energy production. The global production of petroleum-derived plastic has also increased dramatically, from 1.5 million tonnes in 1950 to more than 300 million tonnes in 2014 (Plastics Europe, 2015; Velis, 2014). Some people have described this dramatic increase in the use of plastics as the "Age of Plastics" (Stevens, 2002) or "Our Plastic Age" (Thompson et al., 2009). If the current trend where production increases by approximately 5 per cent a year continues, another 33 billion tonnes of plastic will have accumulated around the planet by 2050 (Rochman et al., 2013).

It is very easy to understand why the volume of global plastics production has already exceeded that of steel in the 1980s (Stevens, 2002). Plastics have a broad range of characteristics that make them a good replacement for

Plastic waste produced and mismanaged



Source: Jambeck, J., R., et al., Plastic waste inputs from land into the ocean, Science, 2015; Neumann B., et. al., Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment. PLoS ONE, 2015.

nearly all traditional materials and they offer qualities unknown in naturally occurring materials. Plastic products and technologies provide huge benefits in every aspect of life, to the point where life without them is almost unthinkable. Many sectors of the economy use plastics, including food and water packaging, a myriad of consumer products like textiles and clothing, electrical and electronic devices, life-saving advanced medical equipment and reliable and durable construction materials (Andrady and Neal, 2009; Thompson et al., 2009).

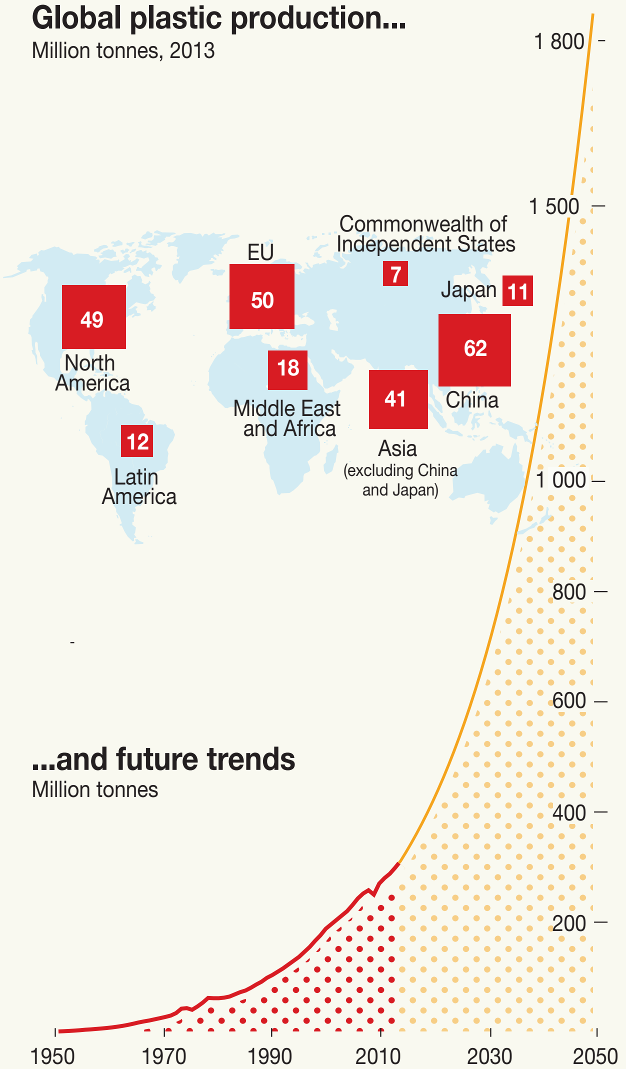
Plastic is convenient as a manufacturing material due to its durability, flexibility, strength, low density, impermeability to a wide range of chemical substances, and high thermal and electrical resistance. But it is also one of the most pervasive and challenging types of litter in terms of its impacts and management once it reaches the marine environment, where it is persistent and widely dispersed in the open ocean.

A growing human population, with expectations of a higher standard of living and generally rising consumption patterns, is concentrated in urban areas across the globe. Our current lifestyle entails increasing consumption of products intended for single use. Plastic manufacturing and service industries are responding to the market's demands by providing low weight packaging and single-use products without plans for end of life management.

Plastic packaging is considered one of the main sources of waste. In Europe, plastic production comes in three broad categories: about 40 per cent for single-use disposable applications, such as food packaging, agricultural films and disposable consumer items; 20 per cent for long-lasting infrastructure such as pipes, cable coatings and structural materials; and 40 per cent for durable consumer applications with an intermediate lifespan, such as electronic goods, furniture, and vehicles (Plastics Europe, 2015). In the US and Canada, 34 per cent of plastic production was for single-use items in 2014 (American Chemistry Council, 2015). In China in 2010, the equivalent figure was 33 per cent (Velis, 2014). However, when we look at the plastic found in waste streams, packaging accounted for 62 per cent of the plastic in Europe in 2012 (Consultic, 2013). This confirms that plastic intended for a single-use product is the main source of plastic waste, followed by waste derived from intermediate lifespan goods such as electronics, electrical equipment and vehicles (Hopewell et al., 2009).

Global plastic production...

Million tonnes, 2013

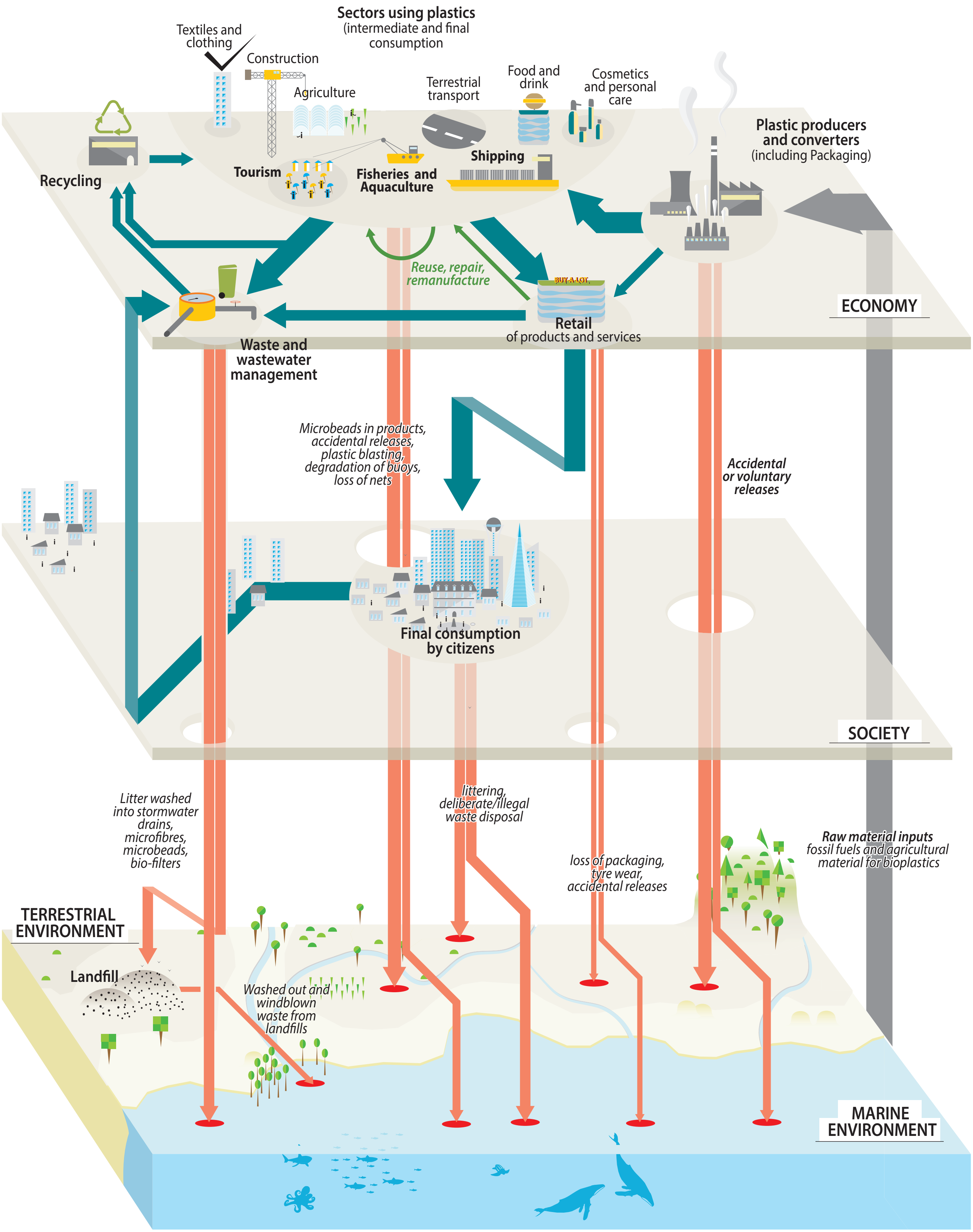


Source: Ryan, A Brief History of Marine Litter Research, in M. Bergmann, L. Gutow, M. Klages (Eds.), Marine Anthropogenic Litter, Berlin Springer, 2015; Plastics Europe

Marine plastic litter, like other waste or pollution problems, is really linked to market failure. In simple terms, the price of plastic products does not reflect the true cost of disposal. The cost of recycling and disposal are not borne by the producer or consumer, but by society (Newman et al., 2015). This flaw in our system allows for the production and consumption of large amounts of plastic at a very low "symbolic" price. Waste management is done "out of sight" from the consumer, hindering awareness of the actual cost of a product throughout its life.

Sustainable long-term solutions to stop increasing amounts of plastic waste from leaking into the environment require changes to our consumption and production patterns. This is a complex task. In order to succeed, campaigns targeting behaviour change need to

How plastic moves from the economy to the environment



take into account differences in demographics (such as gender, age, income and social status).

There are obviously benefits in terms of energy, climate and health from using plastics and therefore the goal should not be to completely move away from plastic, but to use it more efficiently and in an environmentally sustainable way. Even with all the efforts made in the separation and collection of plastic waste, the proportion of plastics that are effectively recycled globally may not even reach 5 per cent of production (Velis, 2014), with large regional variations. The annual volume of globally traded plastic waste destined for recycling was around 15 million tonnes in 2012 (Velis, 2014), with China being a leading import country for plastic scrap recycling. Profound changes are needed to reduce the amount of pollution from plastic waste. Such changes will affect society and industry and, while there are many examples of shifts in the right direction, the magnitude of change needed will take a substantial amount of time.

And yet there is no time to lose. The forecasted impacts of marine litter demand the urgent development of alternative, efficient solutions. Short-term solutions should be implemented to reduce the immediate negative effects, while the necessary long-term changes in consumption and production are incentivised through policy, economic and education/awareness mechanisms. It is clear that plastic has multiple value and functions in our society. There is a need for further research into the demographics of consumer behaviour specific to marine plastic pollution, and willingness to change those behaviours. But given the negative (and unknown) impacts that plastic has on the marine environment, it is necessary to take urgent measures to reduce our dependency of short-lived plastic and to prevent it from reaching the marine environment.

How much plastic waste is produced worldwide

Plastic waste generation rate
Kilograms per person per day

Source: Jambeck, J., R., et al., Plastic waste inputs from land into the ocean, Science, 2015

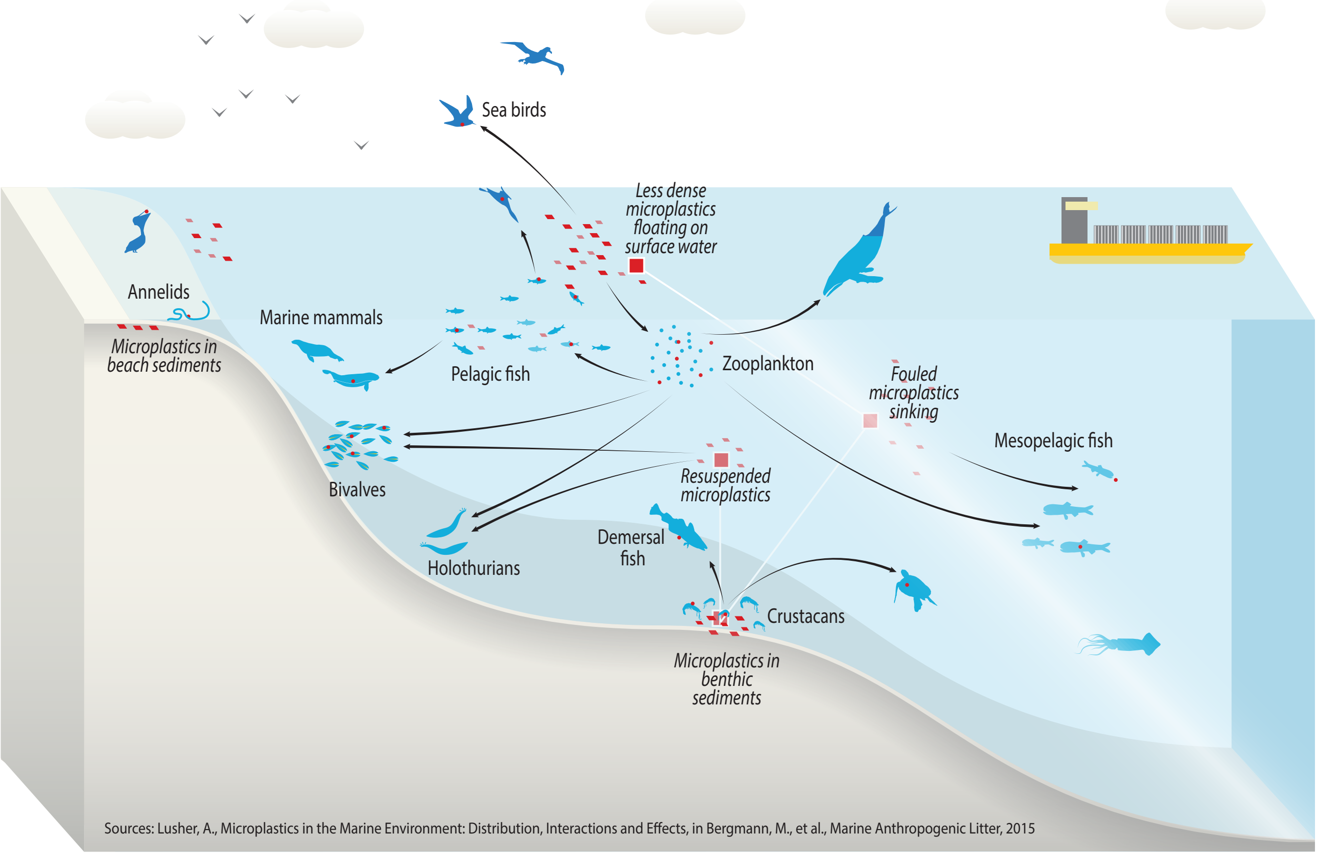
Ecological impacts of marine plastic debris and microplastics

There has been widespread publicity about pollution of the marine environment by plastic debris and its impact on organisms. Images of the brightly coloured plastic stomach contents of dead seabirds and countless whales, dolphins and turtles caught in floating debris or wearing discarded plastic rubbish are routine. But this is not only about large marine creatures swallowing or getting entangled in rubbish; organisms at every trophic level, living both on the seabed and in the water column, are also affected.

The plastic diet

Plastic debris can have similar size characteristics to sediment and suspended particulate matter and can be ingested by filter feeding or sediment ingesting organisms. Lugworms, amphipods and barnacles have all been shown to ingest plastic fragments and fibres (Thompson et al., 2004). Even very small organisms at or near the bottom of the food chain, like filter feeding zooplankton, have been observed in the laboratory to take up microplastics (Cole et al., 2013; Setälä et al., 2014). Zooplankton usually excrete the particles within hours (which is comparable to natural food) but some zooplankton have been found to retain microplastics for up to seven days (Cole et al., 2013). The ingestion of polystyrene particles by zooplankton has been found to significantly decrease their nutritional intake (because they can eat up to 40 per cent less real food) and also their reproductive output (Cole et al., 2015 and Lee et al., 2013). Apart from providing zero energy, a diet of non-nutritional microplastic beads also affects how these organisms deal with food shortages. Usually they instinctively decrease their metabolic rate to save energy when faced with starvation – however this does not occur when the diet contains microplastic beads (Cole et al., 2015).

How plastics enter the food web



Sources: Lusher, A., Microplastics in the Marine Environment: Distribution, Interactions and Effects, in Bergmann, M., et al., Marine Anthropogenic Litter, 2015

Plastic in faeces and other aggregates

The concentration of microplastic at the ocean surface is thought to be lower than expected, suggesting that it is somehow being removed to deep sea areas (Cózar et al., 2014). Microplastics can sink when they acquire ballast. It has been suggested that one mechanism involved is the incorporation of ingested plastic into faecal pellets (Wright et al., 2013; Setälä et al., 2014; Cole et al., 2016). Algal aggregates, which are common in surface waters, can also incorporate microplastics (Long et al., 2015). The faecal pellets and aggregates eventually sink, taking the microplastics with them (Long et al., 2015).

Microplastics have been found in many other filter feeding and sediment ingesting organisms, including amphipods, sea cucumbers, mussels and marine worms (Graham and Thompson 2009; Murray and Cowie 2011; Van Cauwenberghe and Janssen 2014; von Moos et al., 2012; Wright et al., 2015). It appears that some organisms commonly consumed by humans can retain plastic for several weeks (e.g. mussels; Browne et al., 2008) and show varying responses to the ingestion of plastic. For example, the blue mussel has been observed to have a strong inflammatory response and the Pacific oyster has exhibited modifications to feeding behaviour and reproductive disruption (Sussarellu et al., 2016).

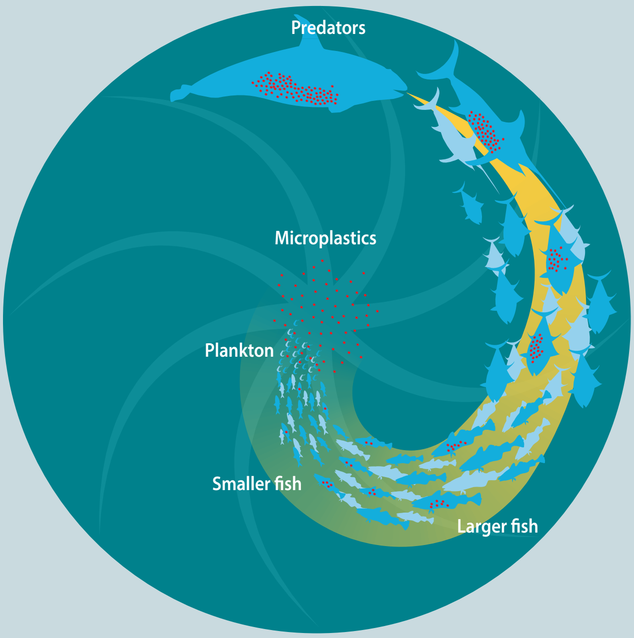
There is much less information on the impact of the microplastics that are increasingly being found in fish, but there is growing concern due to the potential impact on people who eat fish. During the 2009 Scripps Environmental Accumulation of Plastics Expedition (SEAPLEX) in the North Pacific Gyre, a total of 141 fish from 27 species were examined for the presence of plastic particles. More than 9 per cent of the fish had plastic in their gut (Davison and Asch 2011). Similarly, a study of fish caught in the English Channel revealed that more than 30 per cent of those examined had plastic in their gut. It is currently difficult to determine the connection between the health of fish and the presence of microplastics (Foekema et al., 2013; Davison and Asch 2011; Rummel et al., 2016). However, it is generally thought that significant ingestion of microplastic material can, over time, negatively affect the health of fish by falsely satisfying hunger or causing internal blockages (e.g. Wright et al., 2013).

The presence of marine litter in birds, turtles and mammals is well documented. A recent comprehensive review revealed marine litter in 100 per cent of marine turtles, 59 per cent of whales, 36 per cent of seals and 40 per cent of seabird species examined (Kuhn et al., 2015). Despite the large percentage of animals swallowing plastic debris, death as a result of plastic ingestion is probably too infrequent to affect the population structure. However, other effects may be more significant. These include partial blockage or damage to the digestive tract and reduction in foraging due to feelings of satiation, all of which can result in poor nutrition and a consequent decline in health (Kuhn et al., 2015).

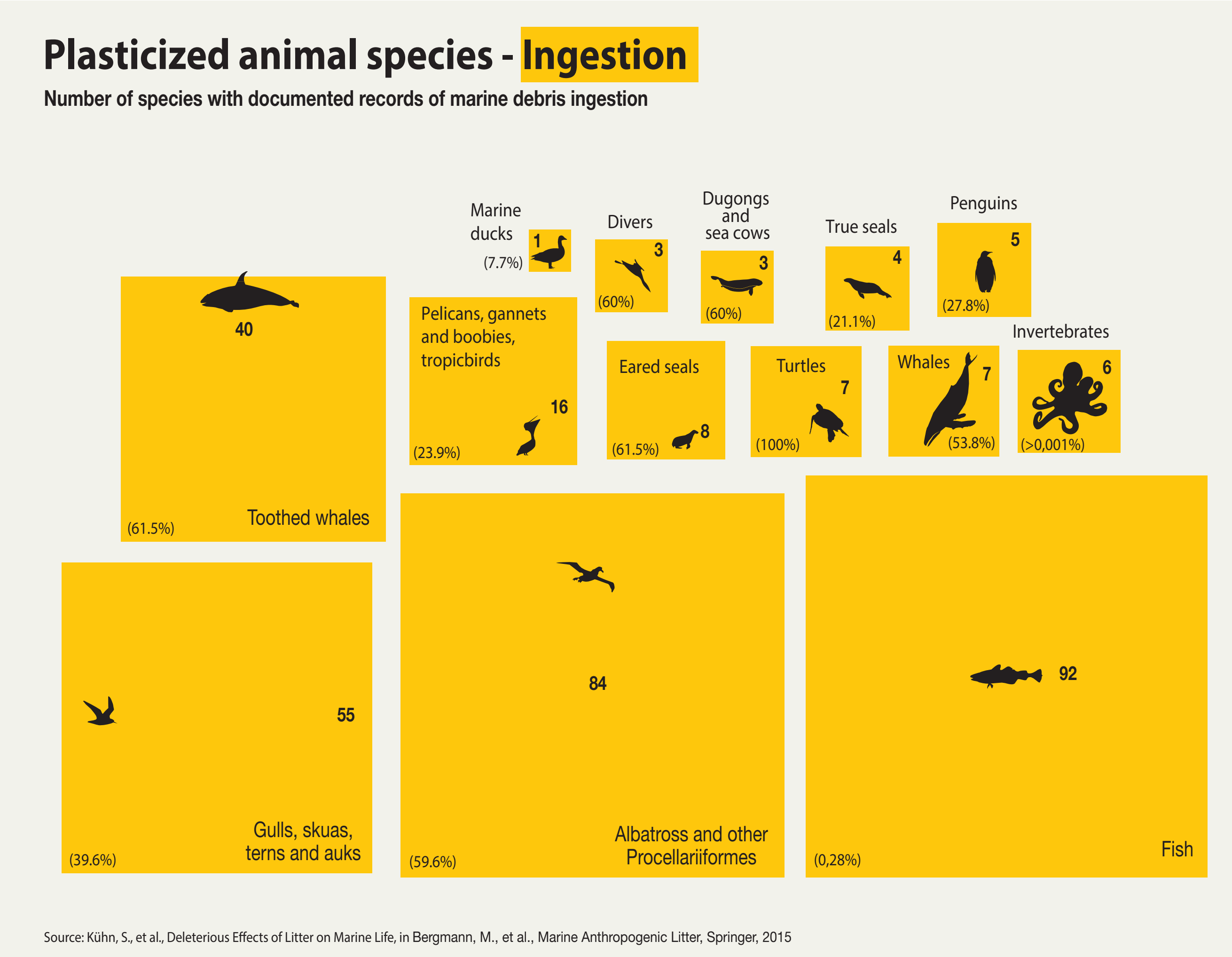
Poisoned by plastic?

Apart from the physical risk from plastic, there is also concern that marine organisms are at risk from the ingestion of hazardous chemicals that are in the plastic or adsorbed on its surface. The ability of plastic particles in the ocean to attract organic chemicals that don't dissolve, which include many well-known toxic substances, has led to a growing number of studies looking at plastics as a source of toxic chemicals in marine organisms.

Plastic bioaccumulation in the food web



Source: Rochman, C., M., The Complex Mixture, Fate and Toxicity of Chemicals Associated with Plastic Debris in the Marine Environment, in Marine Anthropogenic Litter, 2015



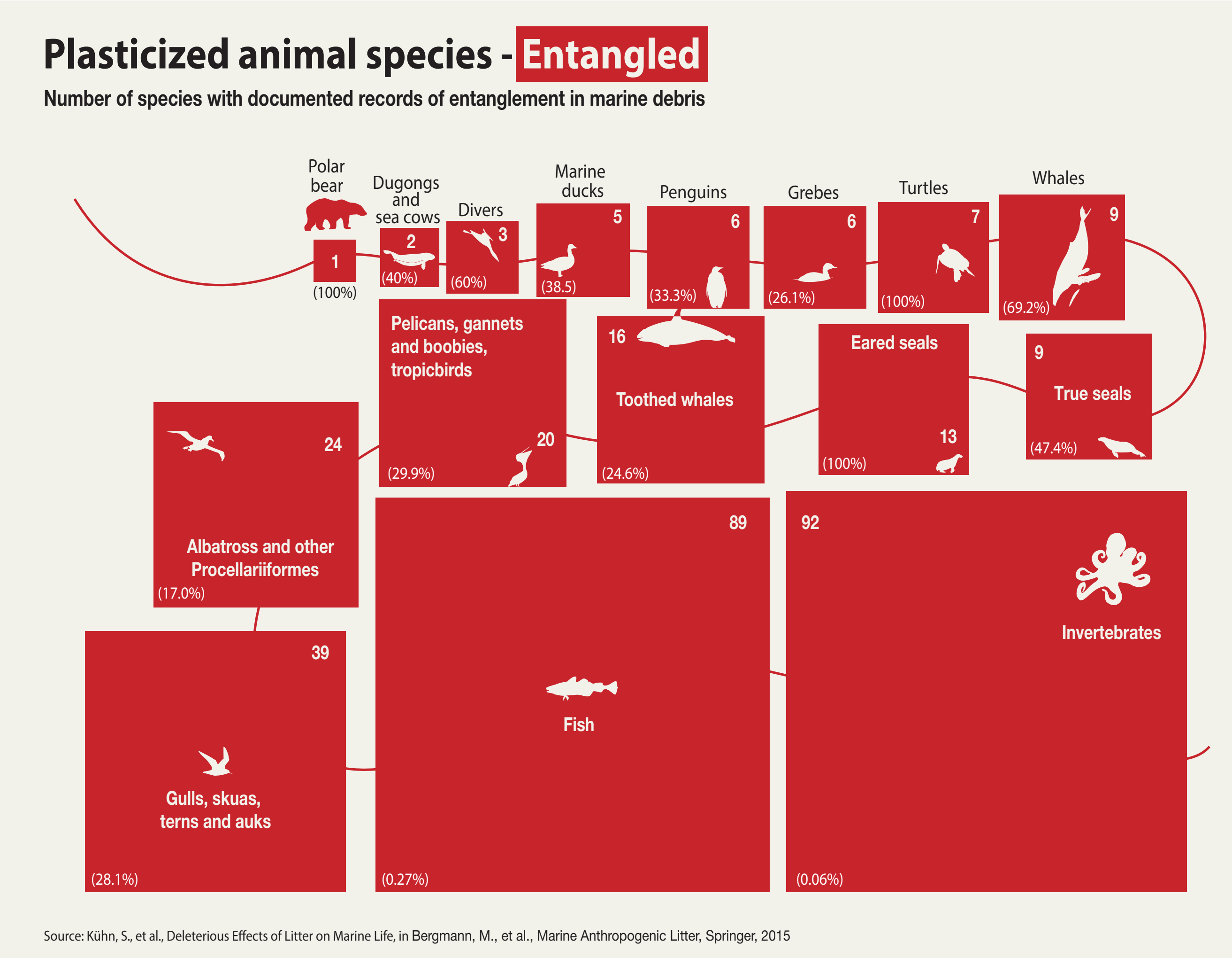
A recent review of microplastics as a vector for chemicals found that the fraction of organic chemicals absorbed by plastics is small compared to other carriers of chemicals in the ocean (these include water, dissolved organic carbon, black carbon and biota; Koelmans et al., 2016 and references therein). The ingestion of microplastics by marine organisms is unlikely to increase their exposure to organic chemicals (Koelmans et al., 2016) but the plastics themselves also release chemicals as they degrade, increasing the overall chemical burden in the ocean.

Caught by plastic

Entanglement in debris is a more obvious and proven risk to marine life than other impacts of litter, which are still subject to debate. More than 30,000 cases of entanglement (in 243 species) have been reported (Gall and Thompson, 2015). Entanglement can cause a quick or a slow death through drowning, starvation, strangulation or cuts and injury that cause infection (Laist 1997). Much of the damage to organisms is caused by discarded fishing equipment – so-called "ghost fishing". It is a problem that affects predominantly higher taxa organisms: whales, turtles, seals, dolphins, dugongs, sharks and large fish. For example, studies examining scarring on whales from the Gulf of Maine indicate that more than 80 per cent of right whales and 50 per cent of humpback whales have experienced entanglement in fishing gear (Knowlton et al., 2011; Robbins and Mattila 2004). In the North West Atlantic, it is estimated that between 1970 and 2009, more than 300 large whales died as a result of entanglement, a significant proportion of them since 1990 (van der Hoop et al., 2012). Northern Australia has a particularly high density of ghost nets (3 tons per km of shore line annually), which pose a threat to endangered marine fauna in the region (Wilcox et al., 2015). It is estimated that more than 8,000 nets collected between 2005 and 2012 could have been responsible for the deaths of more than 14,000 turtles (Wilcox et al., 2015). Ghost fishing entangles species other than those targeted by the fishing gear; it also results in impacts to the targeted species, as the gear continues to trap and catch them without harvesting.

Smothering and other damage

Much of the marine litter entering the ocean is initially



buoyant and floats on the surface; however the ocean floor may be its final resting place (Goldberg, 1997). Large items, including discarded or lost fishing gear, quickly sink to the sea floor. These items can smother benthic organisms, crush vegetation and coral and turn sediments anoxic (Kuhn et al., 2015). Examples include fishing line wrapped around coral colonies causing death, plastic bags directly smothering organisms or reducing light penetration, and large items dragged along the sea floor causing physical damage (Kuhn et al., 2015; Yoshikawa and Asoh, 2004).

Floating away

The artificial habitats provided by floating marine debris can support a diverse marine ecosystem. Kiessling et al. (2015) report that globally, 387 taxa, including microorganisms, seaweed, and invertebrates, have been found on floating litter. They found that, in most of the world's oceans, stalked barnacles (a prominent fouling species) were the most common organisms colonizing floating litter. It is not only large mats of litter that provide a home for marine organisms; one species of water strider has found that microplastic particles provide an ideal site to lay eggs. Goldstein et al. (2012) suggest that the increase in numbers of the pelagic water strider *Halobates sericues* in the region of the North Pacific Subtropical Gyre is a direct result of the increase in hard substrate provided by microplastic.

Floating litter provides an additional dispersal mechanism for natural floating materials such as kelp mats, pumice and wood. Although these rafts of rubbish, moved by the same wind and currents as natural material, do not provide new dispersal pathways, the persistence and wide distribution of large amounts of plastic in the oceans provides greater opportunity for dispersal (Lewis et al., 2005). It has been suggested that debris could play a part in the spread of invasive species. Kiessling et al. (2015) document numerous examples of potential invaders found on marine litter beyond their natural dispersal range. They conclude that changes to the temporal and spatial availability of rafts, caused by the growing quantity of marine litter, probably facilitate the establishment of species in new regions.

Economic and social costs of marine plastic pollution

Marine plastic debris and microplastics have substantial negative effects on marine ecosystems. This in turn affects ecosystem services, the economic activities relying on those services for revenue generation, sustainable livelihoods and the well-being of communities and citizens. The full extent of the impact of plastic pollution on marine ecosystems is still unknown and therefore the economic and social costs are difficult to fully assess. Knowledge is however fundamental to the development of effective and efficient methods for reducing potential impacts (UNEP, 2016c, Newman et al., 2015).

The economic activities directly affected by marine plastic debris and microplastics include shipping, fishing, aquaculture, tourism and recreation (UNEP, 2016c). The fact that these debris are easily dispersed in the marine environment makes it difficult to trace their specific origins and identify how they got there. In some cases, the industries affected by marine litter are also its source (e.g. plastic litter from tourism, fisheries, shipping, etc.) even though they have an interest in addressing the problem. Often the polluters do not bear the cost of polluting. It is however in the interests of many sectors of the economy to find strategies to reduce marine litter, as this can help to reduce the burdens on them.

The only global assessment to date aimed at monetary valuation of the natural costs associated with the use of plastic in the consumer goods industry rates the cost across all sectors to be approximately 75 billion dollars per year (UNEP, 2014). An independent analysis of this dataset revealed that the cost associated to impacts on marine ecosystems could be estimated to be at least 8 billion dollars per year. The food, beverage and retail sectors were responsible for two thirds of these costs. This estimate comprises the revenue loss to fisheries and aquaculture and the marine tourism industries, plus the cost of cleaning up plastic litter on beaches. This upstream approach allows the different sectors to realise their relative impact on the marine environment (risk) and to identify measures that could reduce their use of plastic (opportunities).

There is a clear lack of connection between sectors of the economy producing plastic products and those affected by the inappropriate disposal of those products (principally fisheries, shipping and tourism). There are, however, complex interrelationships between the sectors involved. For example, the fishing industry provides resources for the food industry and the tourism industry depends on (or is a participant in) the food and beverage industries. The shipping industry provides services to the retail, food and beverage industries and is a participant in the tourism industry. These interdependencies, if properly highlighted and utilized, could be pivotal in creating true cross-sectoral engagement in providing solutions to the challenges posed by marine litter.

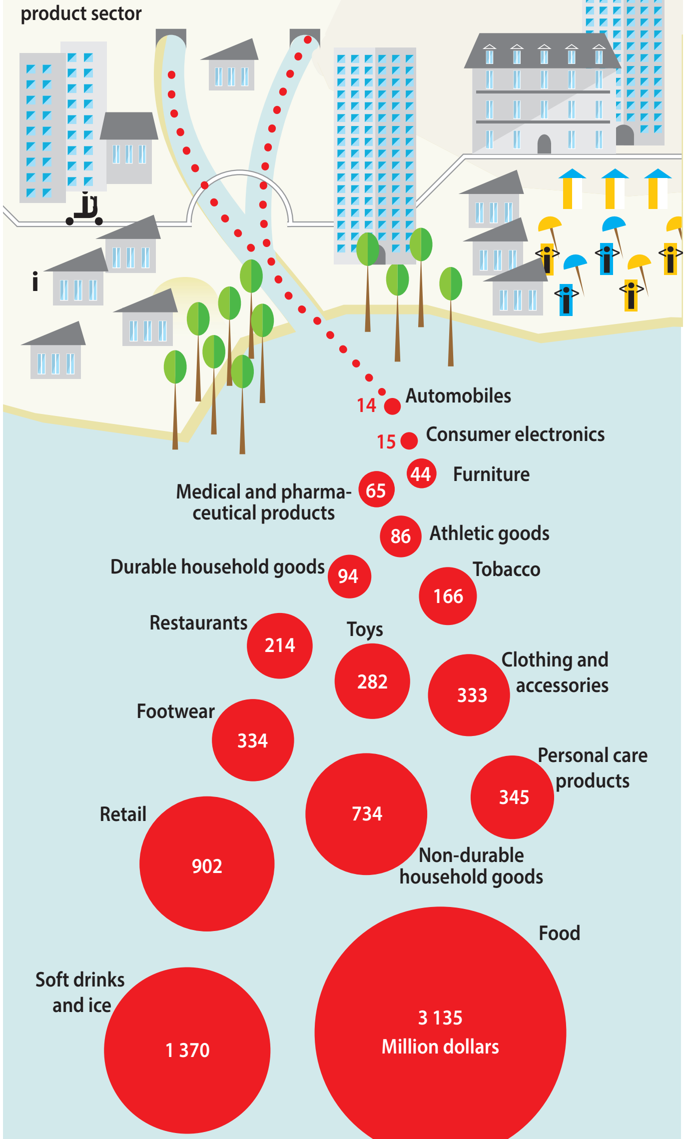
In the shipping sector, marine litter can damage vessels by fouling ship propulsion equipment or cooling systems to the point of causing breakdowns and delays. There are direct costs linked to repairs, rescue efforts, and loss of life or injury, but there are also indirect costs related to loss of productivity and disrupted supply chains, leading to revenue losses. For example, damage caused by litter to shipping is estimated to cost 279 million dollars per year in the Asia-Pacific Economic Cooperation region (APEC, 2009).

In the fishing sector, costs connected to marine litter are due both to damage to vessels and gear and to catch reduction. Vessel damage results primarily from litter sucked into inlet valves and rubbish snared around propellers. Catch reduction results from ghost fishing by discarded gear and mortality related to ingestion of marine litter. The total loss to the industry is difficult to estimate but as an example, the European Union fishing fleet is estimated to lose 81.7 million dollars (61.7 million euros) per year (Arcadis, 2014).

In the tourism sector, losses are related to the pollution of beaches and coasts which can discourage visitors. The reduction in visitor numbers leads to loss of revenue,

The impact of plastic pollution on oceans is at least $8 bn per year

Natural capital cost of marine plastic pollution by consumer product sector



Source: UNEP, Valuing Plastic, 2014

Wyles et al. (2015) conducted an experiment where they asked volunteers to rate photographs of a beach – with or without litter, and with different types of litter. They found that the presence of litter on the beach made it less attractive to the research participants, who rated the photos according to how they made them feel and the likelihood that they would choose to spend time in such a place. The research participants preferred the clean beaches to the littered ones and expressed negative feelings towards the photos with litter. The debris in the photos was either "fishing litter" – ropes, nets etc. from the fishing industry, or "public litter" – items that could have been left by visitors to the beach. Participants reported that both kinds of litter made the landscape less attractive, but the "public" litter even more so.

jobs and livelihoods. In the Asia-Pacific Economic Cooperation region, marine litter is estimated to cost the tourism sector around 622 million dollars per year (McIlgorm et al., 2011).

Alongside the economic costs, there are social costs. These include reduced opportunities for recreational activities, health risks to coastal visitors (cuts from sharp items on the beach or in the water), and loss of the physical and psychological benefits of access to coastal environments (such as a reduction in tension and stress due to experiencing nature and/or physical activity). In areas with poor waste management the costs can be unfairly borne by coastal communities or remote regions, such as Small Island Developing States, that are especially affected by the concentrated accumulation of litter drifting on ocean currents.

As previously mentioned, there is evidence that harmful microorganisms and pathogens can colonize the surface of marine debris (Caruso 2015). Plastics found in rivers have been observed to act as vectors in the spread of pathogens and algal bloom species (McCormick et al., 2014). Keswani et al. (2016) recently reviewed the literature on microbial associations with marine plastic debris and concluded that they may increase human exposure to pathogens at swimming beaches, but more research is necessary to determine the potential for disease transmission.

An area that deserves further consideration is the psychological impact related to the perception of the risks and impacts of marine plastic debris and microplastics. Particular attention needs to be paid to the perceived health risks to consumers from the accumulation of microplastics and associated chemicals in seafood, including possible gender differences in chemical uptake. The risk posed by macro debris to large, emblematic marine fauna (whales, seals, turtles and seabirds) has implications for animal rights. In addition, the ethical implications of polluting natural habitats that have high biodiversity and aesthetic value also need to be considered. The final impact of this is two-fold: (1) the impacts on psychological well-being even if none of the previously mentioned services (recreational or therapeutic) are affected; and (2) potential behaviour change (i.e. reduction in fish consumption and/or consumer attitude towards plastic intensive products) even if there are no existing measured economic or ecological impacts (UNEP, 2016a).

Plastic in the food chain – a threat to human health?

There is growing concern that toxic chemicals from plastic debris, especially micro- and nanoplastics, are making their way into the food chain. But are they harmful? Anthropogenic marine debris has been observed throughout the ocean, from beaches and shallow coral reefs to the deep sea. Plastic particles have been found in hundreds of species of marine organisms, including many species of fish and shellfish sold for human consumption. A recent study found plastic in one out of every four fish purchased from markets in the United States and Indonesia (Rochman et al., 2015). Globally, average per capita fish consumption is nearly 20 kg per year and seafood equates to nearly 17 per cent of the world's protein consumption (FAO, 2014), so there is a potential pathway for human exposure to plastic.

Plastic on the plate

Assessing the risks to human health from marine plastic is a complex process and there is still a lot of debate over the quantity of plastic being ingested from seafood and whether it has the potential to affect the health of consumers. Consumption of filter feeding invertebrates, such as mussels and oysters, appears the most likely route for human consumption of microplastics, because people eat the whole organism including the gut. It has been shown that mussels can retain some plastic in their circularity system for over 48 days (Browne et al., 2008). It is estimated that high consumers of mussels in Belgium could ingest up to 11,000 pieces of microplastic in a year (an average of 90 particles per meal over 122 meals; Van Cauwenberghe and Janssen, 2014). The presence of microplastic particles in seafood could pose a human health risk (Van Cauwenberghe and Janssen 2014; Bouwmeester et al., 2015), especially if, following ingestion, the particles move from the digestive system to come into contact with organs and tissues. However, there is currently no evidence of ingested microplastics moving from the gut into other parts of the human body (Galloway, 2015).

In contrast to microplastics, it is thought that nano-sized material (less than 100 nm) may be more readily absorbed through the digestive system into the body. Evidence for this comes largely from studies investigating the ingestion of engineered nanospheres as a method of drug delivery, where they have been seen to cross the gut barrier and enter the circulatory system (e.g. Hussain et al., 2001). Bouwmeester et al. (2015) reviewed laboratory studies that demonstrate uptake of nanoparticles by marine organisms, including mussels and scallops. However, they conclude that there is insufficient evidence to determine whether the absorbed nanoparticles can go beyond the circulatory system and enter cells. There is also some debate about the extent of nanoplastics in the ocean. It has been suggested that they are produced from the fragmentation of larger plastic particles, helped by both physical and microbial processes (Cozar et al., 2014 and Law et al., 2014). At present it is technically difficult to detect nanoparticles in tissue or in the marine environment, so new detection methods are required to determine the extent and fate of these particles (Bouwmeester et al. 2015).

What about the chemicals?

In addition to the potential physical effects of ingesting plastic, there may also be associated chemical toxicity. Marine debris has been shown to contain a cocktail of chemicals including monomers and additives like flame retardants, antioxidants, UV-stabilizers and plasticizers. There is research that indicates that some of these chemicals can act as endocrine disruptors in humans (reviewed in Talsness et al., 2009). Chemicals of particular concern are phthalates and bisphenol A (BPA), which animal studies suggest may impair reproductive function and be carcinogenic, even at very low doses (Meeker et al., 2009; vom Saal et al., 2007). However, even though phthalates and BPA have been in commercial use for over 50 years, studies into the effects on humans are limited. Several studies have explored possible associations between phthalates and conditions such as altered semen quality and shortened gestation, although data are limited and the results inconclusive (Hauser and Calafat, 2005). A hazard analysis of plastic polymers identified polyurethanes (used in hard plastic parts and

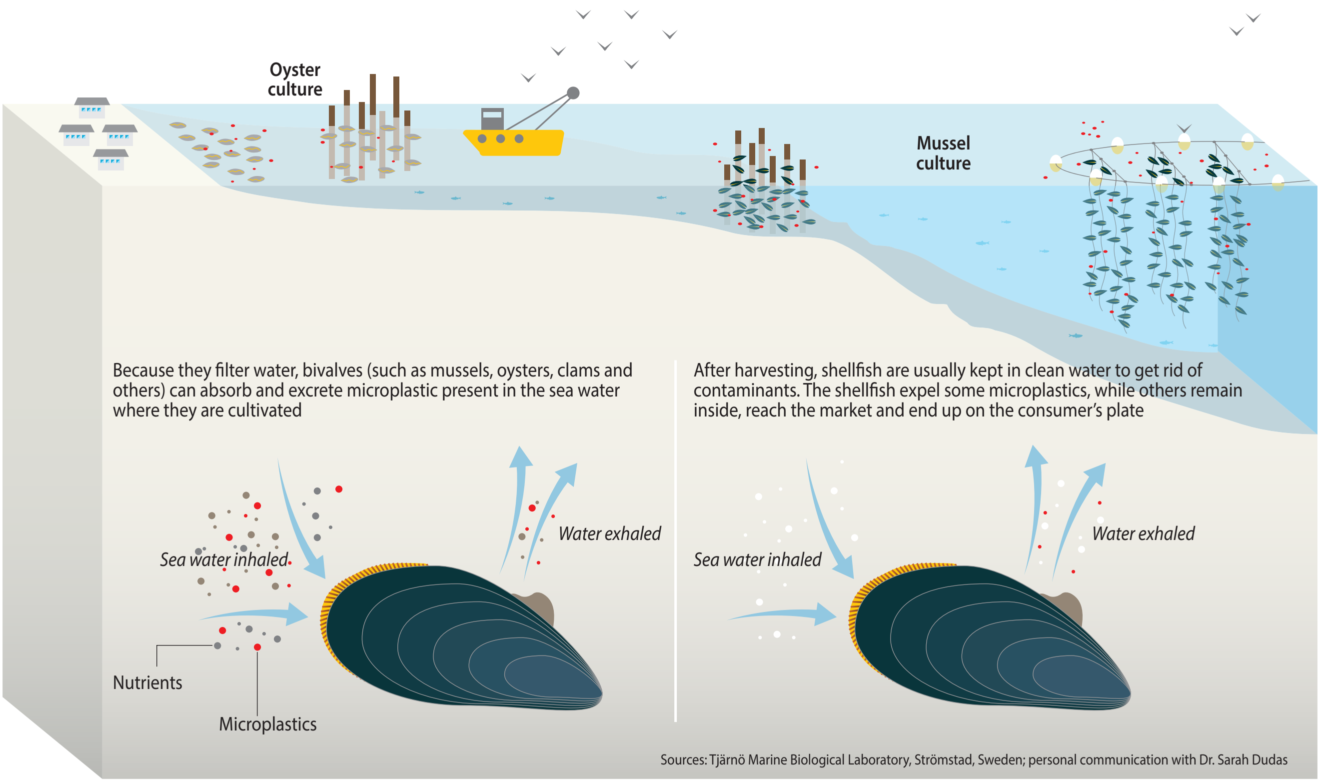
synthetic fibres), polyvinylchloride (PVC used in pipes, bottles and non-food packaging), epoxy resins (adhesives and metal coatings) and styrenic polymers (styrene foam insulation) as posing the highest human health risk (Lithner et al., 2011). These plastic polymers (apart from epoxy resin) are amongst the most common microplastic litter encountered in the marine environment.

Plastic, a magnet for other contaminants and harmful organisms

In the marine environment plastic can be both a source and sink for contaminants. As well as releasing chemicals, microplastics have been shown to adsorb compounds like polycyclic aromatic hydrocarbons (PAHs) and metals from the surrounding sea water. Due to their high surface area to volume ratio, microplastics can concentrate contaminants to orders of magnitude higher than in the surrounding sea water (Mato et al., 2001). Substances referred to as persistent, bioaccumulative and toxic (PBTs), such as dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyls (PCBs) and persistent organic pollutants (POPs) are of particular concern. There is evidence that hydrophobic contaminants such as POPs are more likely to be adsorbed onto plastic polymers than marine sediments (Tueten et al., 2007). Furthermore, older plastic particles have been found to have higher levels of POPs, suggesting that they continue to adsorb and concentrate contaminants for as long as they remain in the marine environment (Frias et al., 2010).

The ingestion of marine debris carrying these concentrated toxins has potential to bioaccumulate up the food chain and enter the human diet. However, although there is evidence of the harmful impacts of these chemicals on marine biota and human health (in men, women and children), there is uncertainty regarding their bioavailability once ingested. There is little research yet available on gender-differentiated effects of these secondary chemicals that are transferred up the food chain to humans along with the microbeads. Bouwmeester et al. (2015) conclude that, from available evidence, the dietary intake of POPs and other additives adhering to marine microplastics will constitute a minor component of exposure to these contaminants compared to other exposure pathways (such as ingestion of crops treated with herbicide, burning of waste, chemical fires and industrial exposure).

An example of how microplastics could end up on a consumer's plate



Sources: Tjärnö Marine Biological Laboratory, Strömstad, Sweden; personal communication with Dr. Sarah Dudas

We all contribute to this problem. Yes, all

One of the major challenges to addressing the increasing amounts of litter accumulating in the marine environment is the fact that its sources are multiple and widespread. There are three main human activities leading to to the leakage of plastic debris to the environment and eventually into the ocean:

- ***Inadequate management of waste and residues*** **generated by practically any type of human activity, which can lead to their accidental release in the environment.**
- ***Intentional littering*** **is the conscious, inappropriate disposal of waste whether industrial, commercial or domestic.**
- ***Unintentional littering*** **includes regular, uncontained procedures related to any extractive, manufacturing, distribution or consumption process that contributes litter stocks to the marine realm.**

Analysis of the human activities causing marine litter is key to organizing responses to prevent it, whether on land or at sea. Analysis of marine litter items, collected for example during coastal clean-up events, can provide some clues to their origins. This information enables us to determine the relative significance of land-based or sea-based activities as sources of debris. The predominance of one or the other depends on the relationship between the distance of the area where litter is accumulated to the areas where source activities are happening (large urban agglomerations, fishing grounds, shipping lanes, etc.), the ratio between the different activities in the source areas, the local geography and physiography (deltas, estuaries, bays, etc.) and local and regional water circulation patterns.

Based on the items most often collected on beaches, it is commonly claimed that the majority (80 per cent) of marine litter is linked to land-based sources. The top ten most collected items are remnants of consumer products or their packaging released into the environment close to large urban or tourist areas (International Coastal Cleanup, 2014). However, the figure of 80 per cent should be used with caution because there is a lot of variation in the composition of litter depending on the location. Marine litter composition data from different sites worldwide show that sea-based sources are sometimes dominant over land-based sources, especially in locations further away from large population and tourist centres (Galgani et al., 2015). The composition of beach litter collected in remote locations may in fact represent an integration of the sources over larger areas and longer time periods. Based on systematic monitoring of 175 sites over several years, the US National Marine Debris Monitoring Program attributed 49 per cent of the items collected to land-based sources, 18 per cent to sea-based sources and 33 per cent to non-identified sources. Regional variations were recorded, with sea-based sources largely dominating on the northernmost east coast of the US (42 per cent sea-based vs. 28 per cent land-based) and Hawaii (43 per cent sea-based vs. 22 per cent land based) (Sheavly, 2007)

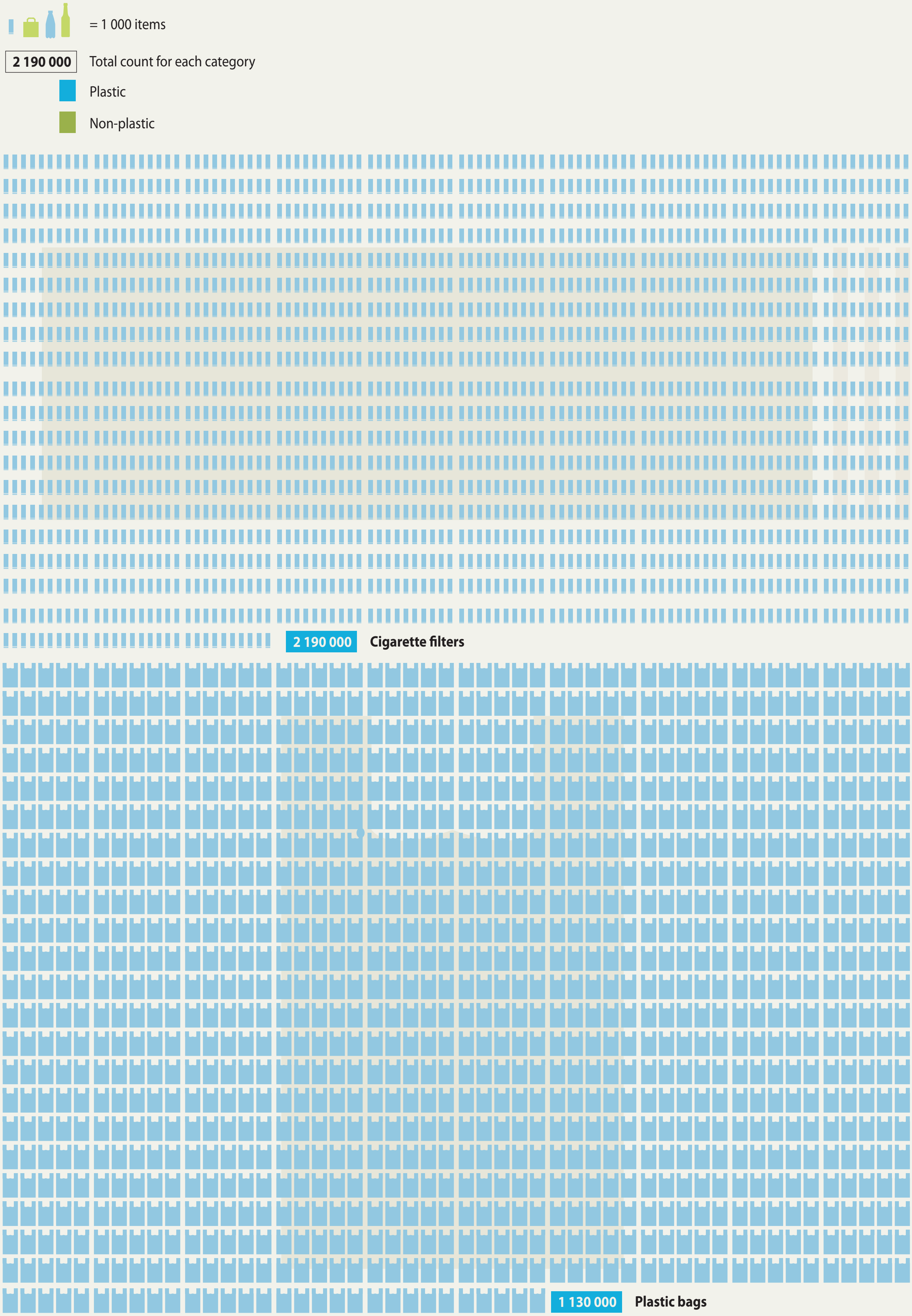
Sources from Land-Based Activities

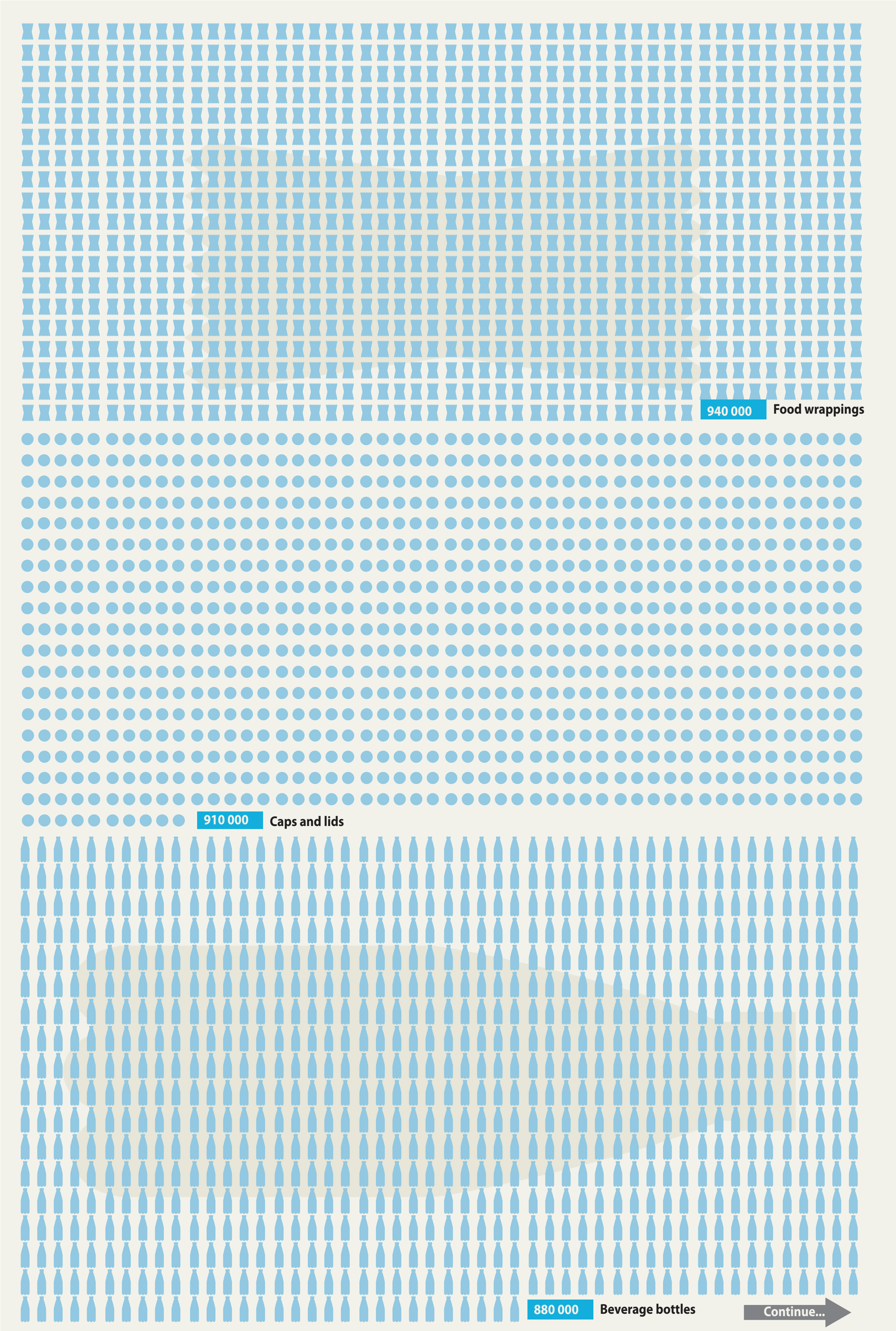
In terms of sources from land-based activities, one of the biggest challenges is proper management of waste. Poor waste management is, without doubt, one of the major sources of marine litter.

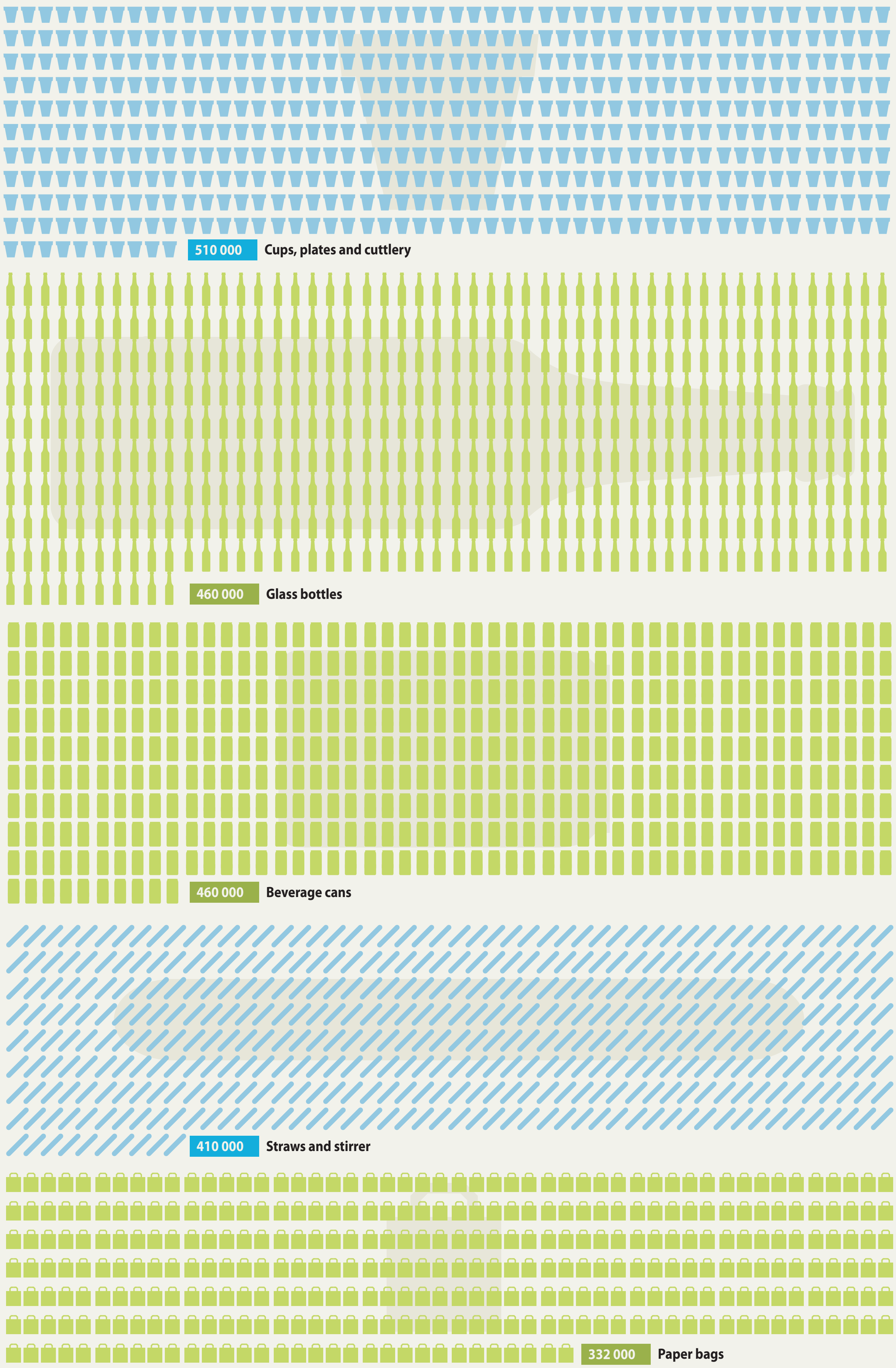
Solid waste management is a complex process involving collection, transportation, processing and disposal. During any stage of the waste management process, release of waste items and particles may occur due to inadequate procedures. In addition, there is waste that is **intentionally littered** (not properly collected) and therefore not included in a waste management system. There were an estimated 32 million tonnes of mismanaged plastic waste in coastal zones worldwide in 2010, resulting in between 4.8 and 12.7 million tonnes of plastic waste input from land into oceans that year. Extrapolating from this figure, by 2025 the total mass of plastic debris added to the marine environment since 2010 would amount to between 100 and 250 million tonnes (assuming business

Most common and visible litter items in beaches

Top ten items collected during the International Coastal Cleanup 2009




940 000
Food wrappings
910 000
Caps and lids
880 000
Beverage bottles
Continue...



Source: Ocean Conservancy, retrived from Bergmann, M., et al., Marine Anthropogenic Litter, Springer, 2015

as usual). The two most important factors controlling the amount of waste that is available to enter the marine environment are the growing human population in the coastal zone, followed by the percentage of mismanaged waste (Jambeck et al., 2015). This estimate of between 100 and 250 million tonnes of plastic is based on the aggregation of national data and does not take into account the international trade of plastic waste destined for the recycling sector, or the potential contribution from the informal non-regulated and non-controlled waste processing sector.

In addition to mismanaged waste the **direct, unintentional release of solid materials into the environment** as a consequence of regular activity applies to those sectors in which a large proportion of operations occur outdoors. This is the case for the extractive, construction, logistics/distribution and tourism industries and also for the plastic manufacture and conversion sector, as it deals with the substance constituting the majority of marine litter.

Of the land-based extractive industries, **agriculture** has the highest plastic demand and greatest waste generation. Plastics take many different forms and applications in agriculture: films used in greenhouses, walk-in tunnel and low tunnel covers, mulching and silage; nets for protection from birds, insects and hail; strapping for bales; pipes for irrigation; bags for fertilizer and packing for agrochemicals. In Europe, during 2014, agriculture accounted for 3.4 per cent of the total plastic demand (2 million tonnes; Plastics Europe, 2015). In 2012, agricultural plastic waste accounted for 5.2 per cent of post-consumer plastic waste (1.3 million tonnes), surpassed only by packaging (15.6 million tonnes) and building and construction (1.4 million tonnes; Consultic, 2013). Despite its low proportion of the total amount of plastic waste, agricultural plastic use is concentrated geographically in certain areas of high productivity which may lead to high levels of pollution. Extensive and expanding use of plastic in agriculture (plasticulture), and particularly in protected horticulture, has been reported worldwide since the middle of the last century (Briassoulis et al., 2013) and is concentrated in southern Europe and the Far East (China, Korea and Japan). The exception to the steady increase recorded worldwide is in China where the area covered by plastic films has increased exponentially since the 1980s, reaching 2.76 million ha covered with plastic greenhouses in 2010 (more than 90 per cent of the area covered by plastic greenhouses worldwide; Kacira, 2011). Agricultural plastic film production in China almost doubled between 2005 and 2010, reaching 1.6 million tonnes, followed by a corresponding increase in plastic waste generation, little of which is so far recycled compared with industrial and domestic plastic waste (Velis, 2014). From 2001 to 2010, an estimated 2-3 million tonnes of plastics were used annually for global agricultural applications (Kyrikou and Briassoulis, 2007).

Building and Construction is the second sector, after packaging, for total plastic demand, representing 21 per cent in China in 2010 (Velis, 2014), 20 per cent in Europe in 2012 (PlasticsEurope, 2013) and 16 per cent in the US and Canada in 2014 (American Chemistry Council, 2015). In Europe, construction-related plastic waste in 2012 (1.4 million tonnes) accounted for only 6 per cent of total plastic waste (Consultic, 2013), compared with 20 per cent of total plastic demand (PlasticsEurope, 2013). The main reason for this is that plastics used in construction often have a significantly longer design life than plastics used for other purposes. Plastic products in the construction sector are designed to be durable and can last between 30 and 40 years before disposal (Bio Intelligence Service, 2011).

Coastal tourism has been recognized as a significant source of plastic waste, very often by direct, deliberate, or accidental littering of shorelines (Arcadis, 2014). Unfortunately it is very difficult to quantify the input from this sector. Proxy indicators, such as earnings related to the sector in particular regions or number of tourist arrivals, can be used as a means of assessing its significance (UNEP, 2015).

Besides agriculture and building and construction, source contributions from all the other major sectors that generate substantial amounts of plastic waste (automotive, electrical and electronic equipment, house wares, leisure, sports, etc.) have recently been assessed in an exhaustive analysis of the social and environmental impacts of plastic associated with 16 **consumer goods sectors** (UNEP, 2014). The analysis assessed the contribution towards potential impacts by the plastic used in the products themselves, but also by plastic in packaging and in the supply chain.

Of the consumer goods sectors analysed, **food, non-durable household goods, soft drinks and retail** account for two thirds of the total natural capital cost per year (the reflection in monetary terms of the environmental damage associated with the use of plastic by each of these sectors). This is a good indication of the sectors which constitute major sources of plastic and therefore impact on the environment. These sectors use plastic intensively and produce products with a short lifespan which enter the waste stream soon after being produced.

When assessing natural capital cost to marine ecosystems, the same four sectors (**food, soft drinks, retail and non-durable household goods**) alone are responsible for three quarters of the natural capital cost. This indicates that consumer products and services may constitute major sources of marine litter.

Sources from Sea-Based Activities

Unfortunately, no modern global estimates are available for **ship-generated waste**. In 1975, the US National Research Council produced a global estimate for ship-generated waste based on detailed estimations of crew and passenger populations (person-days per year). This showed estimates of domestic solid waste generated by all kinds of vessels, including fishing vessels (National Academy of Sciences, 1975). Non-cargo related waste amounted to 0.76 million tonnes per year, which demonstrates the potential significance of the contribution from this source. Of this total, only ca. 5,000 tonnes (0.7 per cent) were estimated to comprise plastic. Although these estimates are 40 years old, and from before the introduction of regulations preventing garbage pollution from ships (MARPOL Annex V), they are the only way to gauge the relative significance of the contribution from mismanaged waste from ships, compared to mismanaged waste from land.

A major source of marine plastic from the **fisheries sector**, including aquaculture and recreational fishing, is from **abandoned, lost or otherwise discarded fishing gear (ALDFG)**. The quantity is estimated at less than 10 per cent of global marine litter by volume (Macfadyen et al., 2009) but it can vary a lot geographically. Jang et al. (2014) studied the annual flow of marine debris in South Korea and concluded that three quarters of the annual marine debris input, or nearly half the annual total, comprised lost fishing gear. ALDFG has increased substantially over past decades with the rapid expansion of fishing and fishing grounds, and the transition to synthetic, more durable and more buoyant materials used for fishing gear (Gilman, 2015). Nets and long lines are particularly abundant in target fishing areas such as submarine canyons, seamounts, banks and ocean ridges (Tubau et al., 2015). Gillnets and fishing traps/pots may be the most common type of ALDFG, although netting filaments may also be common in some locations. Fishing gear is abandoned, lost or otherwise discarded due to adverse weather, operational factors during retrieval, gear conflicts, illegal, unregulated and unreported (IUU) fishing, vandalism/theft, and the absence of access to shore-based collection facilities. Weather, operational fishing factors and gear conflicts are probably the most significant factors but the causes of ALDFG are poorly documented and not well understood (Macfadyen et al., 2009).

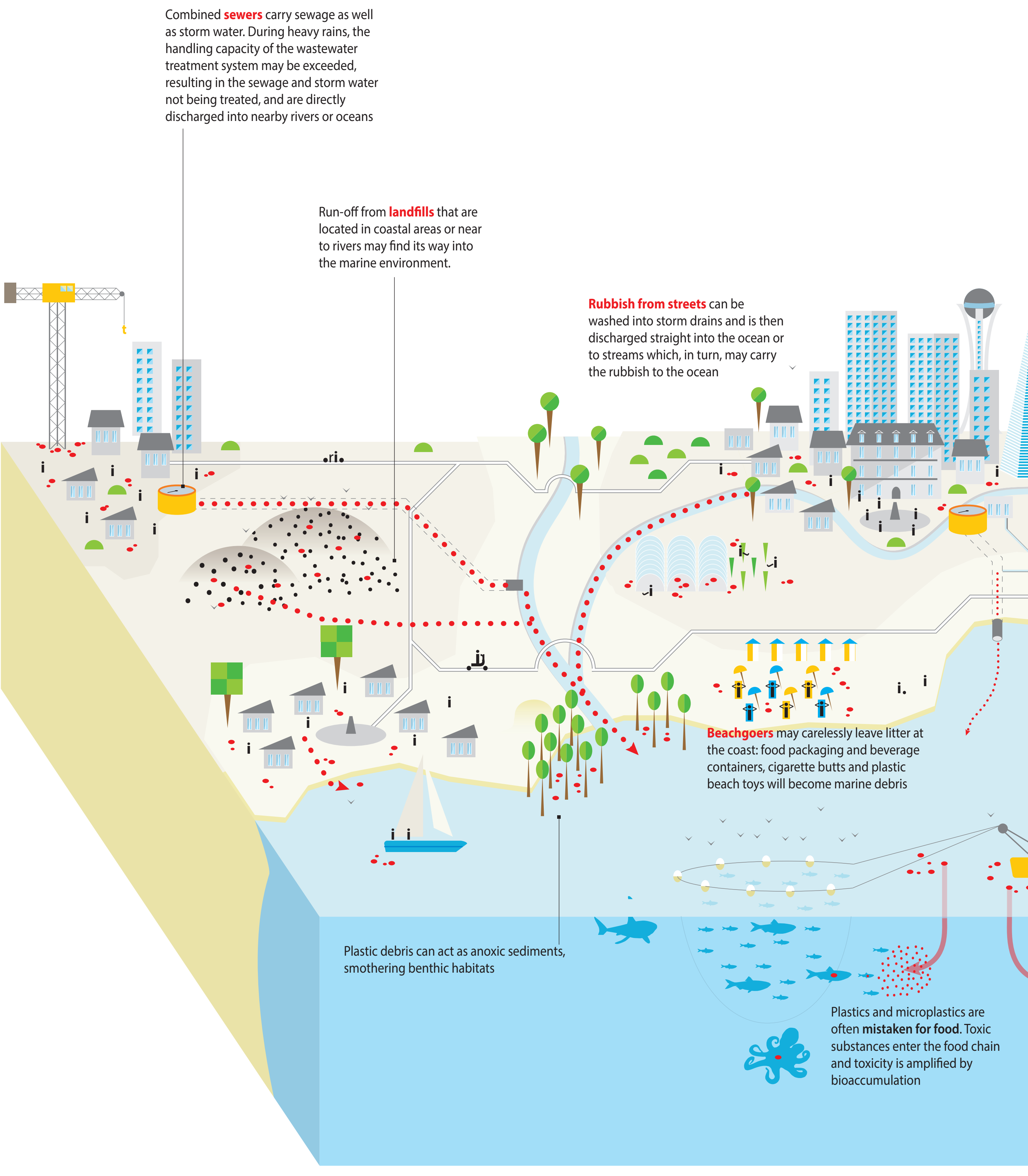
The overall contribution to ALDFG from **aquaculture** is probably limited due to its static nature. Nevertheless, in areas where aquaculture is intensive lost cages, longlines, poles and other floating and fixed items are all sources of plastic debris. There are no global estimates of the levels of ALDFG from aquaculture (Macfadyen et al., 2009). Jang et al. (2014) also studied the contribution from expanded polystyrene buoys (the most common debris item associated with large-scale oyster and seaweed aquaculture), which account for 7.5 per cent (almost 4,400 tonnes) of the inflow of debris from sea-based sources. Debris from sea-based sources in South Korea constitutes almost two thirds of the annual flow of debris into the ocean (approximately 91,000 tonnes in 2012). Marine debris studies in the coastal areas of southern Chile (Hinojosa and Thiel, 2009) have pointed to mussel and salmon aquaculture as the main sources of floating marine debris (polystyrene floats and salmon food sacks).

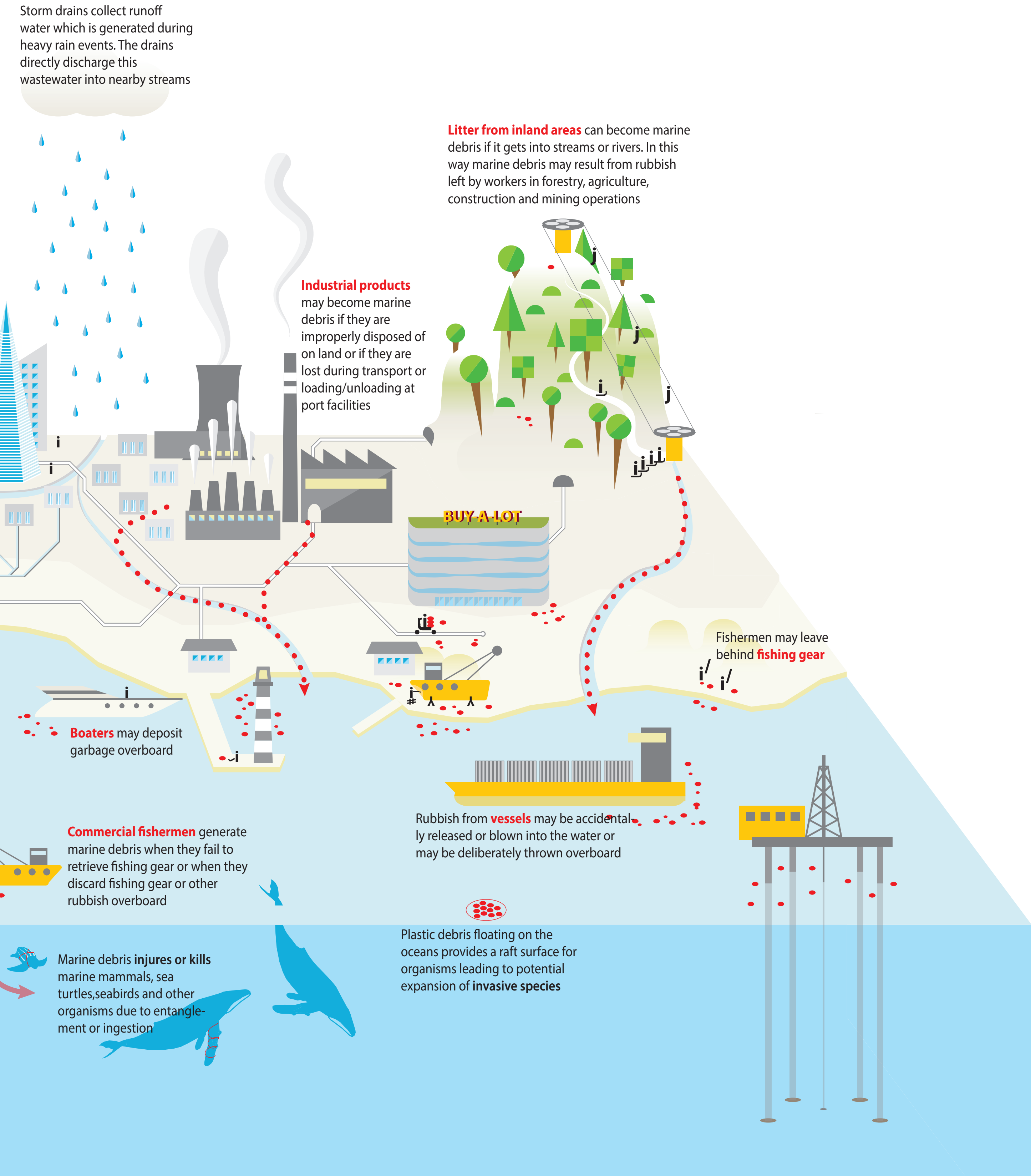
Recreational fishing can be a substantial local source of ALDFG in areas where it is popular. For example, estimates of derelict lobster traps (made of steel frames and synthetic nets) in southern Norway suggest that, of approximately 25,000 traps deployed every season, about 10 per cent are lost. Recreational lobster fishers represent about 80 per cent of Norwegian lobster fishery and have a high rate of trap loss (close to 50 per cent; Kleiven, pers. comm). Of about 2,500 traps lost annually, more than 2,000 are lost by recreational fishers.

Besides mismanaged waste and fishing gear, fishing and aquaculture activities can also lead to **unintentional littering** of ship equipment, such as ropes and other plastic securing devices and packaging materials.

The **shipping industry** also constitutes an important source of marine litter. Cargo ships may, in the event of unforeseen circumstances, lose all or part of their cargo at sea. Estimates based on a survey carried out between 2008 and 2013 point to an average of less than 1,700 containers lost at sea each year due to accidents including catastrophic events (more than 50 containers lost in a single event). On average, 14 out of every million transported containers are lost at sea. For comparative purposes, if we assume that all the containers lost would be 40 feet units and were loaded to 90 per cent of their maximum load capacity, and that 10 per cent of the load was plastic materials, containers lost at sea every year would only contribute around 4,000 tonnes of plastic. This figure is of the same order of magnitude as the amount of mismanaged waste from vessels and three orders of magnitude lower than land-based sources.

Plastic debris in the ocean: a multiplicity of sources and pathways




Storm drains collect runoff water which is generated during heavy rain events. The drains directly discharge this wastewater into nearby streams
Litter from inland areas can become marine debris if it gets into streams or rivers. In this way marine debris may result from rubbish left by workers in forestry, agriculture, construction and mining operations
Industrial products may become marine debris if they are improperly disposed of on land or if they are lost during transport or loading/unloading at port facilities
BUY-A-LOT
Fishermen may leave behind fishing gear
Boaters may deposit garbage overboard
Commercial fishermen generate marine debris when they fail to retrieve fishing gear or when they discard fishing gear or other rubbish overboard
Rubbish from vessels may be accidentally released or blown into the water or may be deliberately thrown overboard
Plastic debris floating on the oceans provides a raft surface for organisms leading to potential expansion of invasive species
Marine debris injures or kills marine mammals, sea turtles,seabirds and other organisms due to entanglement or ingestion

One incident involving the loss at sea of plastic pellets has been recorded, in connection with Typhoon Vicente in July, 2012. On that occasion, 150 tonnes of pellets from six containers were lost at sea (about half of the pellets were recovered two weeks later; ENS, 2012). No data is available summarising spills involving plastic pellets, granules or resin powder carried as bulk or bagged cargo.

In addition to mismanaged waste and accidental losses of cargo, the merchant shipping industry, including cruise and ferry boats, can also contribute through **unintentional littering** of ships' securing equipment. Dunnage, the inexpensive materials used to load and secure cargo during transportation (wrapping film, pallets, straps, dunnage bags, etc.) can pose a challenge to ship operators when it is not in use, as it requires proper storage space and may be accidentally lost overboard if not properly secured. A large portion of these materials are made of plastic.

The 1975 estimate by the US National Academy of Sciences also included cargo-related waste. In fact, this category of waste was by far the most significant contributor among sea-based sources, accounting for 5.6 million tonnes out of an annual total of 6.4 million tonnes of waste from sea-based sources (National Academy of Sciences, 1975). For comparison, assuming that only 10 per cent of this waste stream would be mismanaged and discharged overboard (in 1975 it was assumed that all would be discharged overboard) and that only 10 per cent of it would be plastic, its contribution to the annual input of plastic litter would be 56,000 tonnes which is one order of magnitude greater than sea-based domestic mismanaged waste and two orders of magnitude lower than input from land-based sources.

The shipping industry relies on a series of services delivered at the coastline for it to be able to operate. These include construction, maintenance and scrapping carried out in **shipyards** or along coastlines, docking, cargo loading and off-loading, passenger embarkation and disembarkation, resupplying, and residue and waste off-loading. Most activities are carried out in **harbours** and all may contribute marine litter through mismanaged waste, including wrecks and abandoned vessels, and through unintentional littering.

Finally, legal and illegal dumping at sea of other wastes generated through maintenance and other activities is also a source of marine plastic. Emissions from off-shore installations (oil and gas platforms) are also a potential source of marine litter. The contribution from these two last sources has been assessed mostly in terms of the contribution of microplastic particles which are discussed separately below.

Microplastic sources

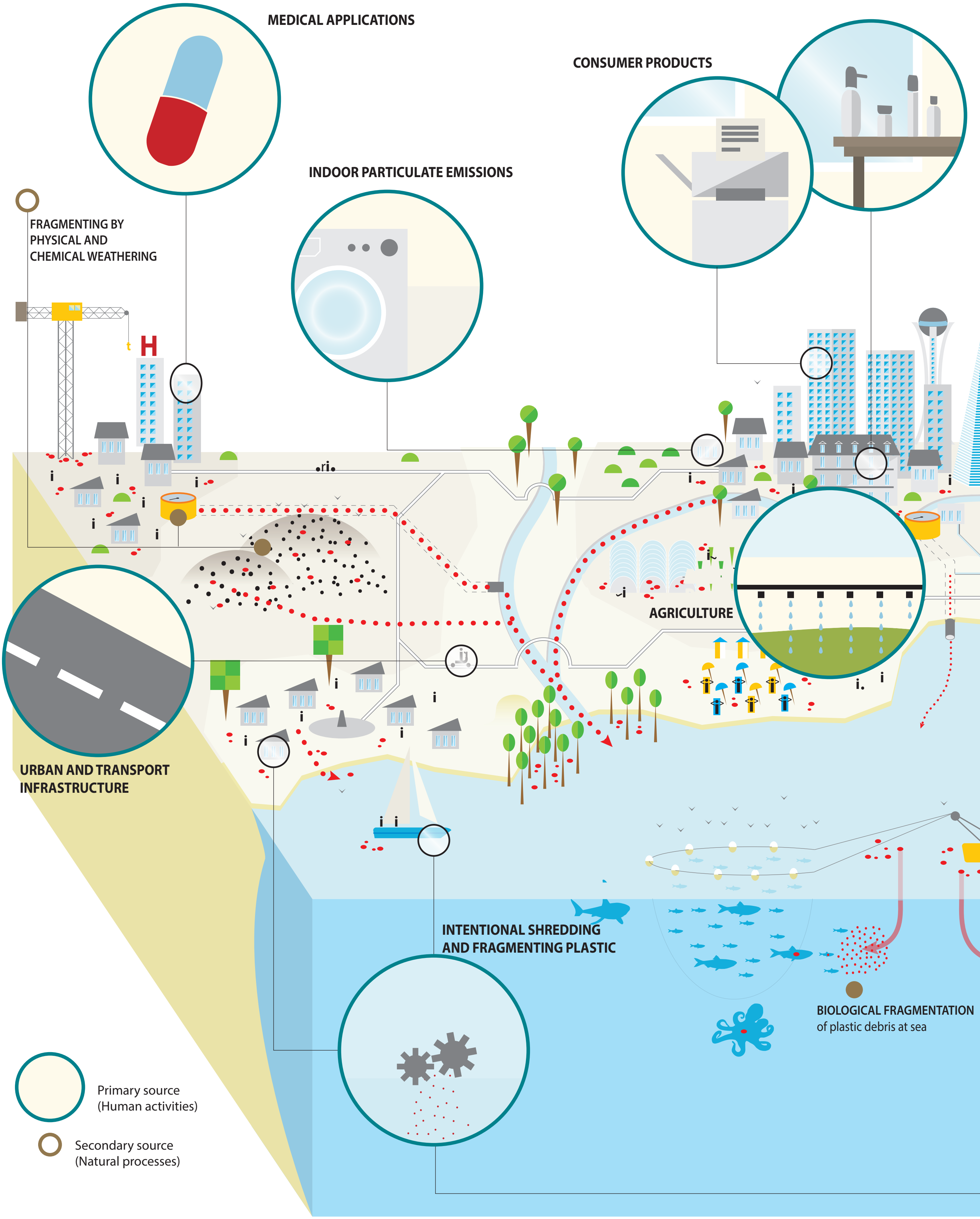
Due to its size and variety of sources, the characterization of microplastic is even more complex than for large plastic debris. There are two types of microplastics particles: those which have been intentionally made (primary sources) and those that result from fragmentation and weathering of larger objects (secondary sources; GESAMP, 2015; Thompson, 2015; RIVM, 2014). For microplastics originating from primary sources it may be possible to identify the specific source and, therefore, identify mitigation measures to reduce their input into the environment (GESAMP, 2015).

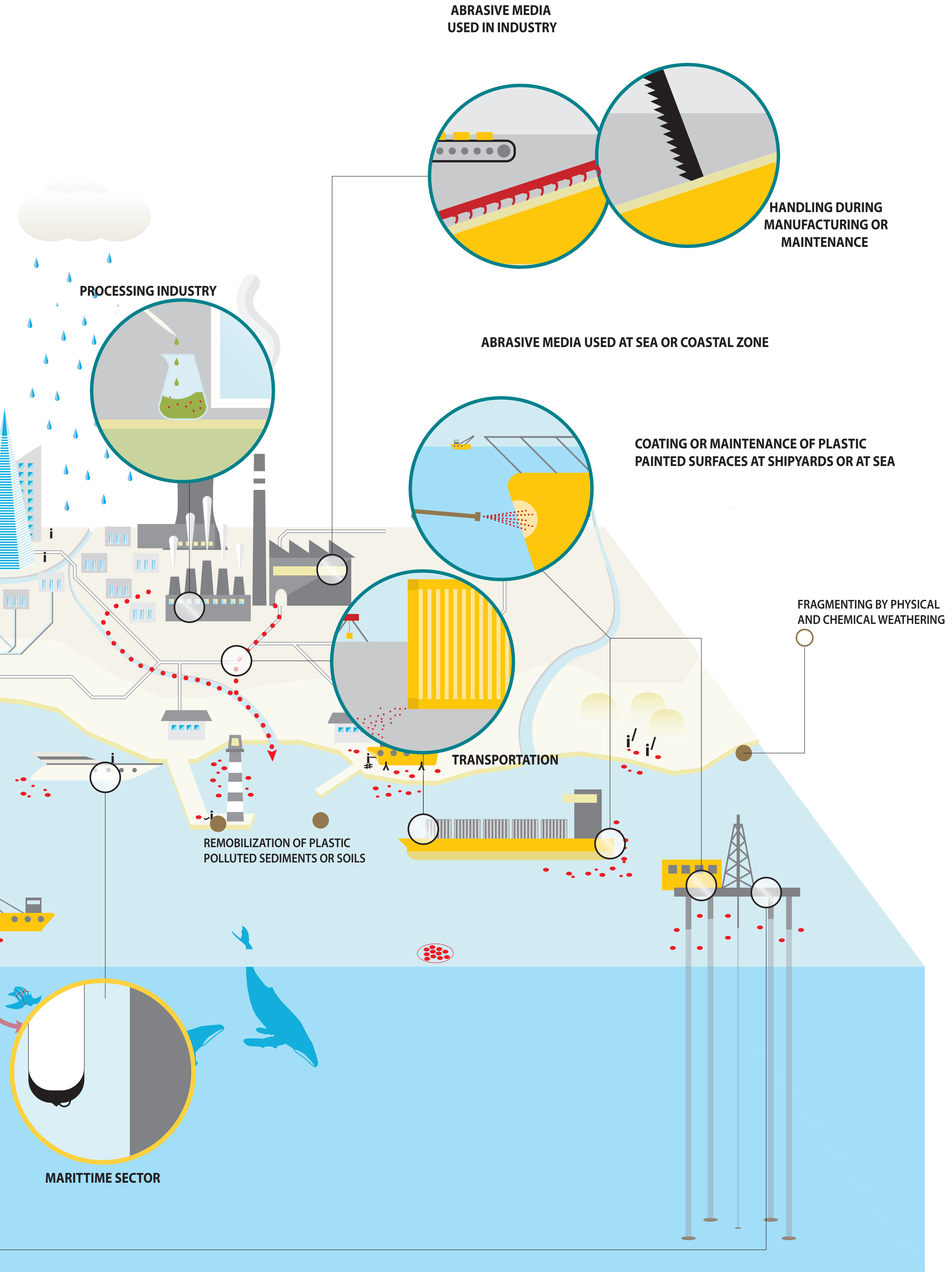
Small plastic particles, within the microplastic size class, are created for items such as personal care products (it is estimated that users of facial scrubs in the United States may be responsible for the discharge of 263 tonnes per year of polyethylene microplastic; Napper et al., 2015) or as abrasive media for cleaning applications. They also result from the unintentional release of intermediate plastic feedstock (i.e. pellets, nurdles or mermaid tears) and occur as by-products of production or other processes. The latter includes probably the largest variety of sources – from particulate emissions from industrial production or maintenance of plastic or plastic-based products, to the release of dust and fibres, to the wear and tear on any plastic products during normal use. This includes particles made by cutting, polishing or moulding during the production of a plastic-based product, emissions during application or maintenance of plastic-based paint, fibres released from synthetic textile products during washing, or rubber particles released from the wear of tyres on roads.

Unfortunately no global estimates are available for the direct input of microplastics into the marine environment. Attempts have only been made to estimate the emissions from certain countries and sources. For example, hundreds of tonnes of polyethylene microbeads from personal care products are emitted annually into the aquatic environment in the US (Gouin et al., 2011) and 8,000 tonnes of microplastics from different sources are emitted annually in Norway, of which about half are thought to reach the marine environment (MEPEX, 2014). The gradual identification of direct sources of microplastic and the need to use crude assumptions in achieving estimates make comparison difficult. Nevertheless, this provides a good sense of the potential order of magnitude of the problem.

In addition to direct input of microplastics resulting from human activities, plastic debris already present in the environment can be a very significant source of microplastics. Plastic debris will progressively become brittle under the action of ultraviolet light and heat and then fragment under physical action from wind and waves into tiny microplastic pieces (Andrady, 2015). Due to the abundance of plastic debris in the marine environment this is likely to represent a major source of microplastic (Andrady, 2011) in future years, even if prevention measures drastically reduce the inflow of large objects. Processes that produce marine microplastics include fragmentation of plastic debris in the sea by physical and chemical weathering; biologically mediated fragmentation of plastic debris at sea or in the coastal zone through digestion in birds and other macrofauna; boring and transport ashore allowing increased physical and chemical weathering; and remobilization of plastic polluted sediments or soils.

How microplastics are generated



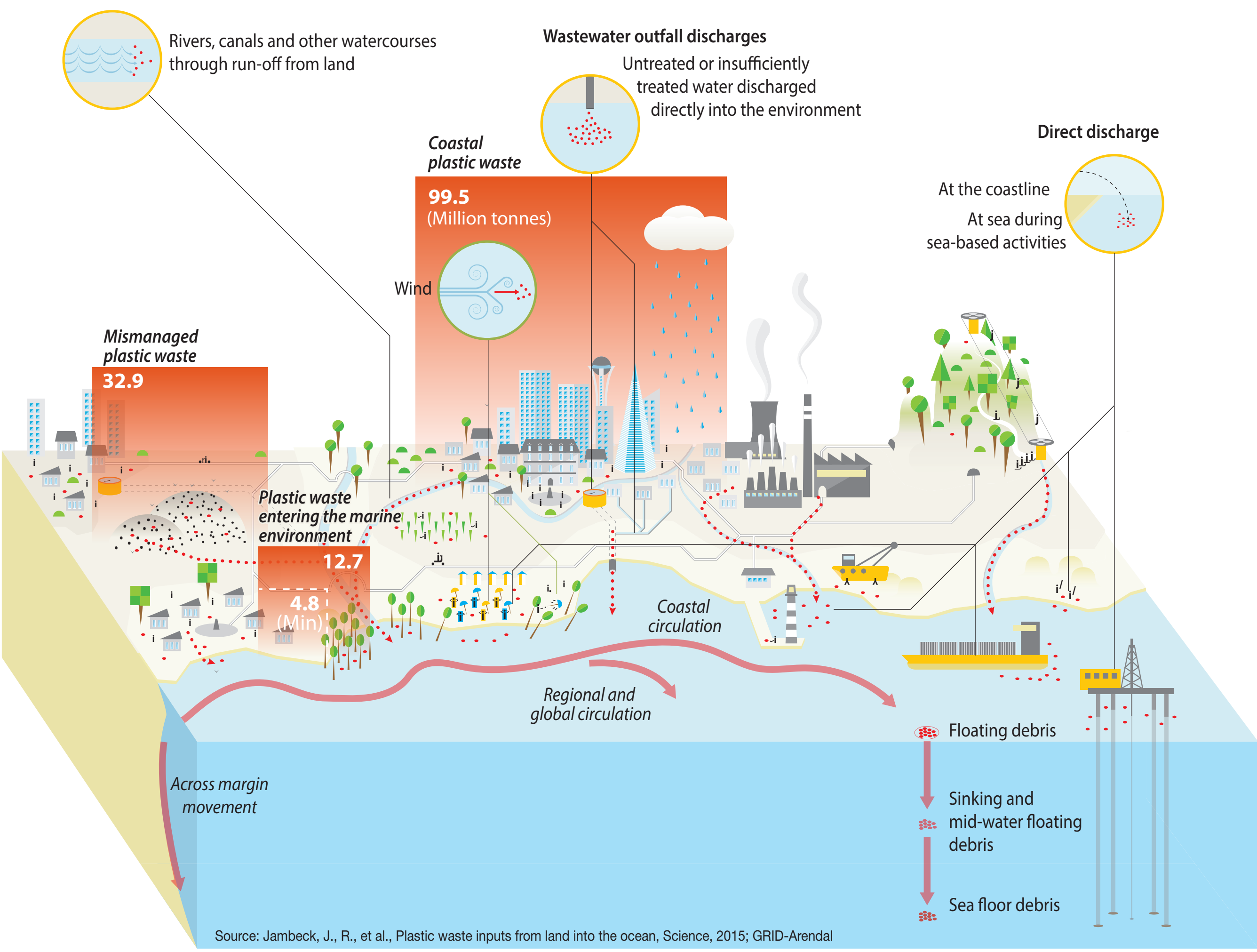

ABRASIVE MEDIA
USED IN INDUSTRY
HANDLING DURING
MANUFACTURING OR
MAINTENANCE
PROCESSING INDUSTRY
ABRASIVE MEDIA USED AT SEA OR COASTAL ZONE
COATING OR MAINTENANCE OF PLASTIC
PAINTED SURFACES AT SHIPYARDS OR AT SEA
FRAGMENTING BY PHYSICAL
AND CHEMICAL WEATHERING
TRANSPORTATION
REMOBILIZATION OF PLASTIC
POLLUTED SEDIMENTS OR SOILS
MARITTIME SECTOR

Final destination: The Ocean…

All material that erodes and washes off the land will end up in the marine environment. This includes solid materials that constitute marine litter. Understanding the role and importance of the different pathways is crucial to prioritizing efforts to reduce the amount of debris and microplastics reaching the ocean.

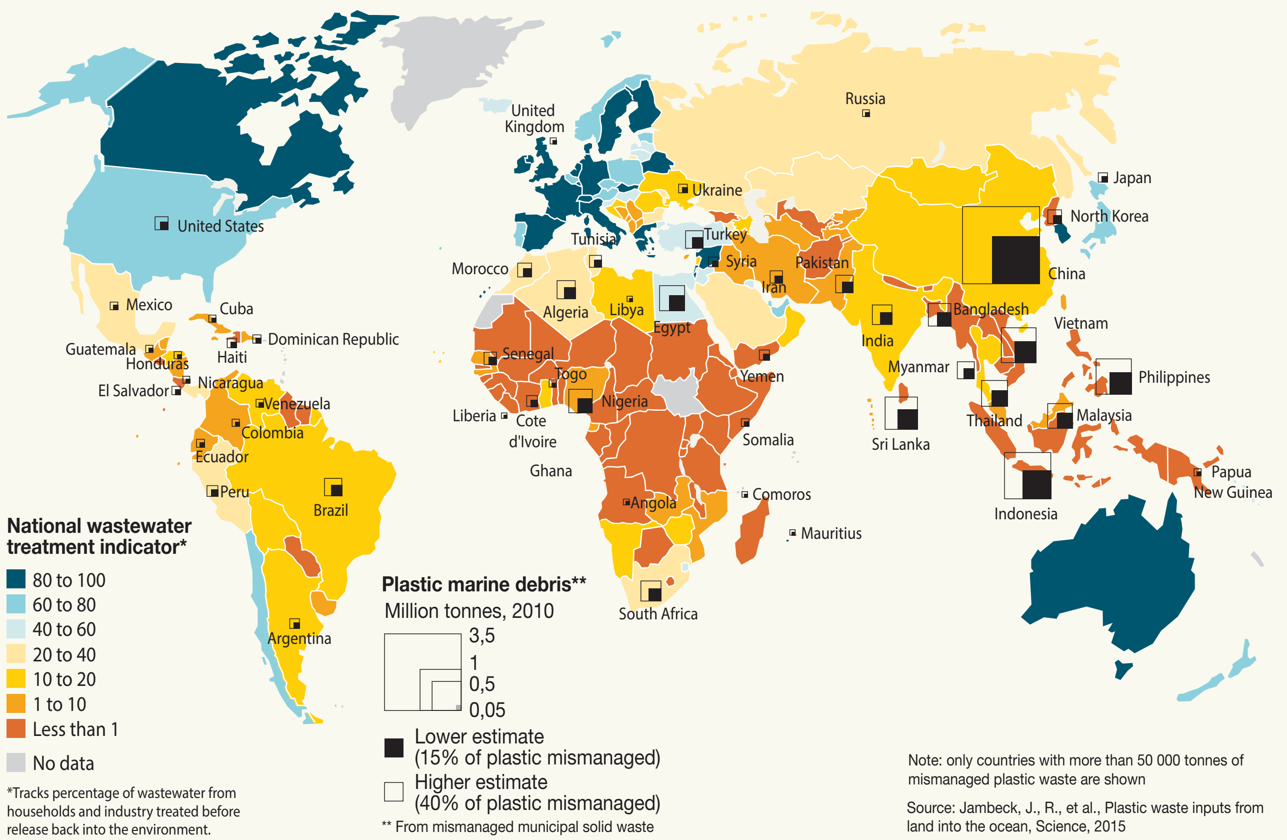
Debris released by **human activity** on land can be washed by surface runoff or blown by wind into **rivers and other watercourses** and ultimately be transported into the ocean. Debris can also be directly dumped or discharged from boats or sewage plants into rivers (Rech et al., 2014). Plastic is very efficiently transported downstream due to its near-neutral buoyancy and may reach the ocean after only a few days (Kabat et al., 2012). Rivers transport plastic debris and, because the average journey is much shorter than the time needed for plastic to degrade, the majority ultimately reaches the ocean. Debris can also become stranded on riverbanks or entangled in vegetation; it may then be remobilized by wind or surface runoff to continue its journey downstream (Williams and Simmons, 1997). During high discharge events caused by heavy rainfall or human-controlled water releases, plastic and other debris can be exported far offshore from the river mouth. Dispersal of debris is also more efficient along coasts that experience high wave energy and/or large tides or other dynamic current regimes (Galgani et al., 2000; Carson et al., 2013; Lechner et al., 2014; Rech et al., 2014).

Pathways and fluxes of plastics into the oceans



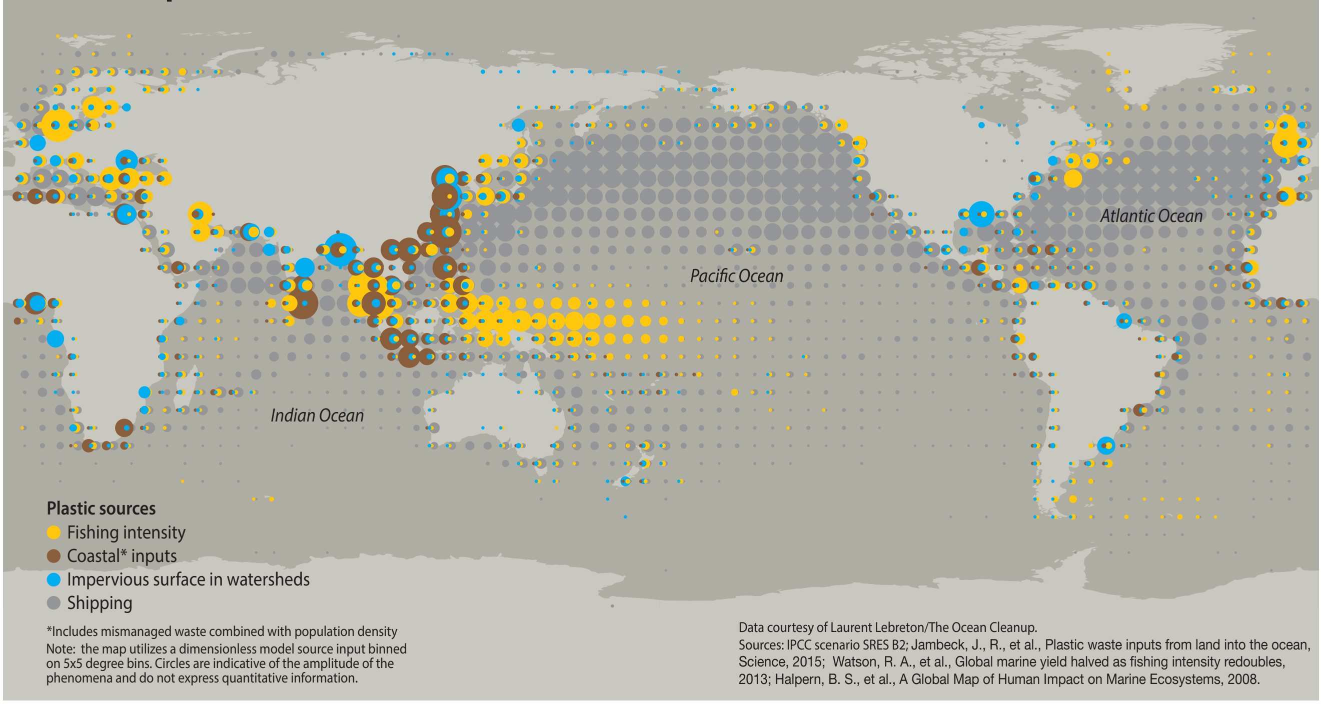
Source: Jambeck, J., R., et al., Plastic waste inputs from land into the ocean, Science, 2015; GRID-Arendal

Plastic input from municipal solid waste and wastewater



Despite knowledge of the role played by rivers, there are no global estimates of the amount of man-made debris reaching the ocean at river mouths. Therefore, of the estimated 4.8 to 12.7 million tonnes of litter which enter the marine environment in 2010 from land-based sources within a 50 km-wide coastal zone (Jambeck et al., 2015), the proportion delivered by rivers is unknown. Debris originating more than 50 km inland from the coast would also need to be added to the figures above. The quantity and composition of anthropogenic debris delivered by a

Plastic input into the oceans



particular river also depends on the intensity and character of the socio-economic activities and population density in the river basin. The implementation of environmental protection and waste treatment measures may help to reduce the leakage of debris. The distribution and extent of impervious surfaces (built-up areas) in watersheds has been used as a proxy for the input of plastic debris through watercourses, as it is directly related to both urbanization and runoff volume (Lebreton et al., 2012).

It is assumed that much less plastic debris is transported by wind than by rivers. There has therefore been much less investigation into input through this pathway. However, wind transport of plastic debris may be highly significant, particularly in arid and semi-arid areas with reduced surface runoff and dry and windy conditions. Wind may be an important localized pathway for lightweight debris, particularly from waste dumpsites located near or at the coast line, or beside watercourses. During intense storms such as hurricanes, wind can mobilize debris that would not normally be available for transport and carry it directly into rivers and the ocean (Lebreton et al., 2012). Wind can also provide an efficient pathway for the transportation of microfibres and small plastic particles, such as from tyre wear, across the land-ocean interface.

Wastewater effluent can be an important **human-mediated pathway** for plastic debris to reach riverine and marine environments. If the sewage collected is not treated thoroughly, or not treated at all, debris will be released into the environment. This means the smallest pieces of plastic can easily escape wastewater treatment plant filters. Entry from sewage discharge can peak during storm events when the capacity of the treatment facilities is surpassed and the wastewater is mixed with storm water and bypasses sewage treatment plants. The significance of sewage pathway contributions to river environments is illustrated by the higher abundance of plastic debris and sanitary products near the bottom in the vicinity of sewage treatment outfalls than elsewhere (Morritt et al., 2014). An environmental performance index, recording the percentage of wastewater treated and the proportion of the population connected to the sewage network, was recently calculated at country level (Malik et al., 2015). It showed the highest performance index for Europe and North America (ca. 65 and 50 respectively), intermediate for the Middle East, North Africa and East Asia and the Pacific (ca. 35 and 25), and low (< 10) for Latin America and the Caribbean, sub-Saharan Africa and South Asia. The average income of countries correlates with the performance indicator, as high income countries have on average a high performance indicator of ca. 65, whereas lower income countries have performance indicators below 15.

The direct discharge of debris from **sea-based activities** into the marine environment is a significant pathway for both the coastal region and the open ocean. Maritime transport, recreational navigation, fishing and aquaculture are the main human activities at sea which may lead to the release of marine debris. The geographical distribution and intensity of these activities (e.g. along main shipping routes) provide good proxies to assess input from sea-based activities.

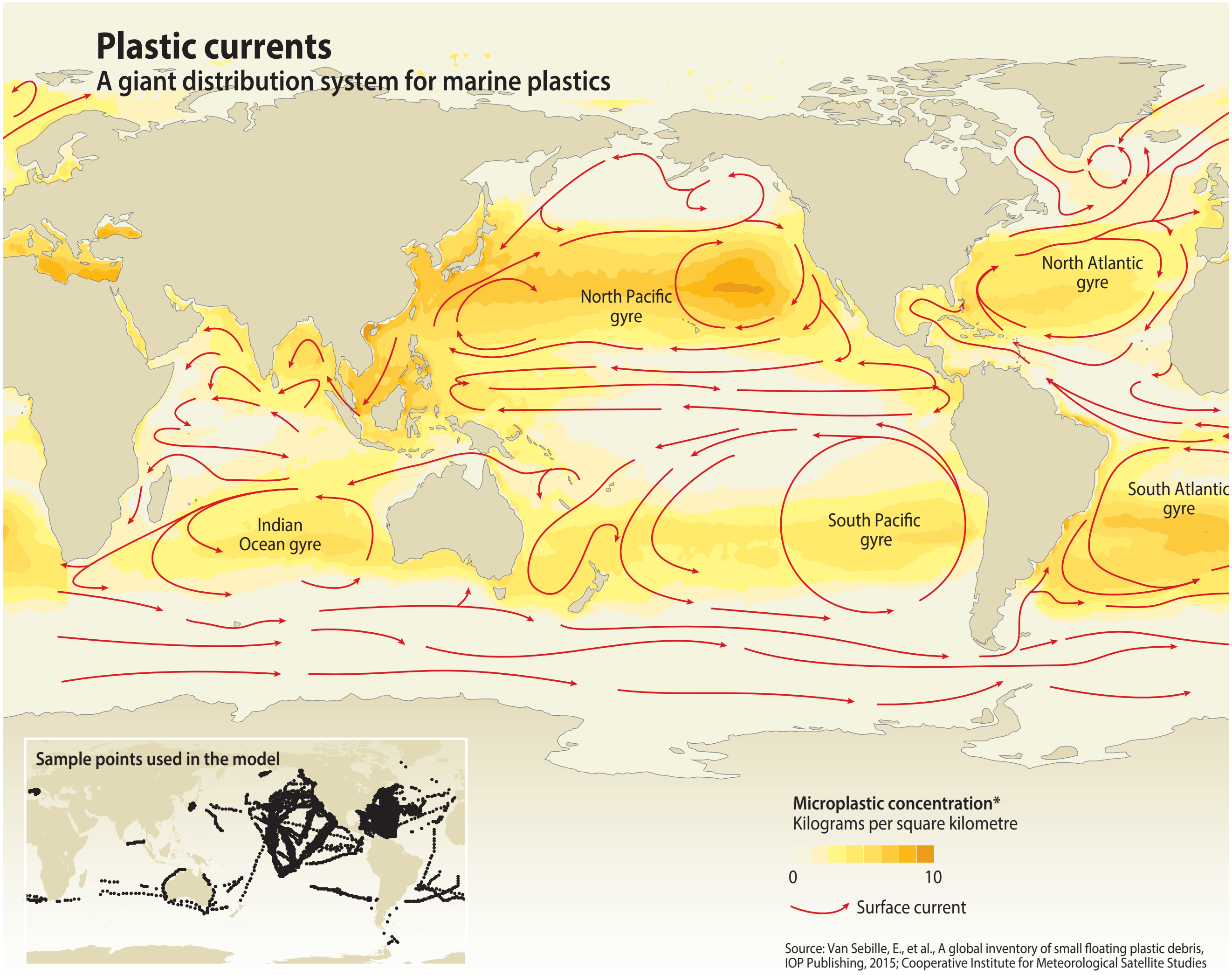
My litter your problem, your litter my problem

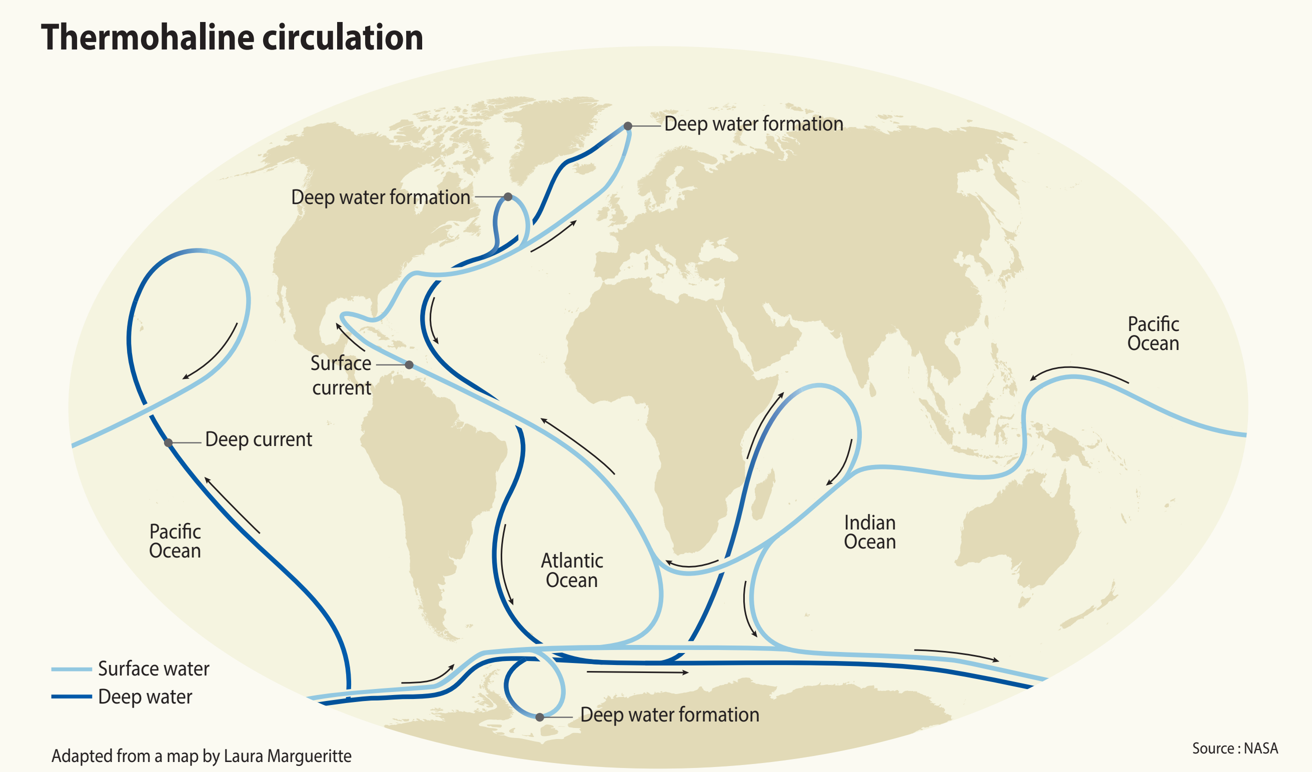
Discarded plastic moving around the ocean – on the surface, in the water column and on the sea floor – sometimes comes to rest. The geographical distribution of marine plastic debris is strongly influenced by the entry points and the different transport pathways, which are in turn determined by the density of plastic debris coupled with prevailing currents, wind and waves (Rech et al., 2014).

Debris found in a location at any moment in time will be a mixture of locally-derived material plus particles that have been transported by current, wind or wave. More than half of the plastic that gets into the marine environment is less dense than seawater, so until it acquires some ballast (often from the accumulation of organic particles or marine organisms), it floats. Once discarded, plastic can accumulate close to its point of entry into the ocean or it can move long distances, ending up in remote locations far away from its entry point. This, combined with the slow degradation rate of most plastic, means it can drift around the ocean for a long time, becoming a true transboundary pollution problem.

Surface dispersion

Surface circulation in the ocean is dominated by five large circular currents, called gyres – the North Atlantic, South Atlantic, North Pacific, South Pacific and Indian Ocean gyres. The currents around these gyres are primarily driven by wind and are the major transport mechanism for the dispersal of floating plastic debris (Barnes et al., 2009).





The water approaching the centre of the gyre eventually has to exit and it does so by flowing downward, sinking to depths of a few hundred metres. Plastic brought to the centre of the gyre by the constantly spiralling water does not travel downward with the escaping water because it is too buoyant. Instead, it stays behind, trapped in the converging current (van Sebille, 2015). Over time this gathering process has led to the formation of five great litter accumulation regions associated with each of the gyres (Law et al., 2010, 2014; Cózar et al., 2014; Eriksen et al., 2014; van Sebille et al., 2015). In these areas of converging surface circulation, plastic debris occurs in much higher concentration than in other areas of the ocean – up to 10 kg per square km (Cózar et al., 2015; van Sebille et al., 2015).

Recently, marine litter has also been observed in the Arctic region (Bergmann et al., 2015) where an additional region with high plastic concentration could be under formation (van Sebille et al., 2012). The concentration of marine litter in the Arctic could increase if floating plastic is transported into the polar regions from the North Atlantic, facilitated by melting sea ice (Bergmann et al., 2015). The Southern Ocean, which is generally considered to be one of the most pristine regions on the planet, is also a site of marine litter. Beach surveys on Antarctic islands reveal that marine debris, mostly consisting of plastic, is accumulating at rates up to four times higher than previously estimated (Eriksson et al., 2013).

In addition, enclosed or coastal seas, with densely populated coastal zones and limited exchange with the open ocean, can be zones of accumulation of plastic debris. Modelling efforts have identified the Mediterranean, South East Asian seas and Bay of Bengal as coastal zones with increased concentration of debris and microplastics (Cózar et al., 2015; UNEP, 2016a).

Models examining the movement of plastic from land-based sources across different regions also point to connections between oceanic basins and gyres, with particles moving from one gyre to another and across oceanic basins in a matter of years. For example, particles released in West Africa could reach the western coast of South America and the Caribbean within one to three years and the North Atlantic Gyre in four to five years (UNEP, 2016a). Of course, the major patterns of global surface circulation are subject to high temporal and spatial variability and surface waters are eventually mixed due to wave and wind action. This leads to short-term changes in plastic concentrations across the horizontal and vertical dimensions of the ocean (Reisser et al., 2015).

Deep transfer and accumulation

Plastic debris does not remain on the surface forever. Eventually it starts to sink. Cold, dense water sinks in the North Atlantic and Southern Ocean, driving what is often referred to as the ocean conveyor belt or thermohaline circulation. This deep water circulation pattern couples with the subtropical gyres and redistributes cooled waters towards the deep ocean layers. The combination of these currents could provide a mechanism for

enhanced vertical dispersion of near-neutrally buoyant plastic particles and debris; further research is required.

The transfer of plastic debris and microplastics towards deeper parts of the ocean has also been documented across continental margins. Here, near-bottom transfer, especially through deep sea canyons, has been linked to accumulation of debris and microplastics along these submarine canyons and adjacent deep sea areas (Pham et al., 2014). In addition to flows triggered by gravity, another efficient mechanism for debris transfer is the enhanced downwards circulation caused by overcooling and evaporation of surface waters on the continental shelf, and their cascading along deep sea canyons (Woodall et al., 2014, Tubau et al., 2015).

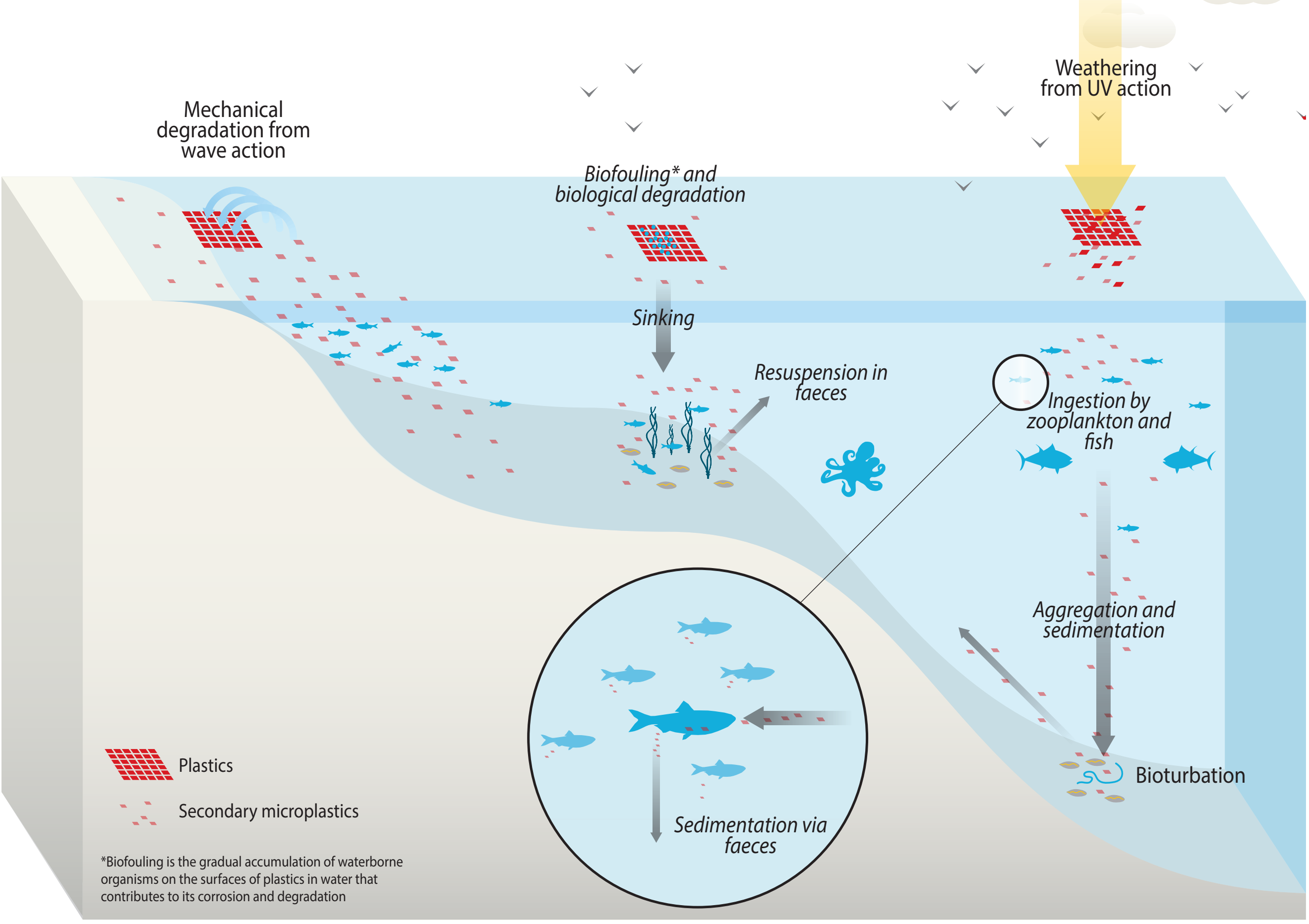
Particle dynamics and the role of organisms

In addition to physical redistribution linked to wind, waves, and surface and deep currents, a whole other suite of biological and mechanical processes influences the distribution of plastic debris and microplastics in the ocean.

Among biological processes, ingestion by all kinds of organisms plays a role in the redistribution of plastic particles within the ocean, as particles may be released again in other areas of the ocean when organisms shift location – even outside the marine environment, for example when seabirds bring debris to land. Vertical downward migration of organisms in the water column following night-day cycles has been shown to play a crucial role in exporting carbon away from surface waters (Ducklow et al., 2001) and this could well be the case for microplastics too (Cózar et al., 2014). Fouling by algae and other colonising organisms such as molluscs also plays a role in the redistribution of plastic particles, as it can increase the density of particles and make them sink towards the sea floor. Remineralization, the reverse process due to degradation of the colonising organisms during sinking, can also affect the particle's buoyancy and cause it to float towards the surface again (Wang et al., 2016).

Finally, several mechanical processes influence the size spectrum of marine plastic items, which affects their interaction with the physical and biological processes. Plastic objects exposed to solar UV radiation and oxidation are progressively eroded and fragmented by wind, wave or biological action. On the other hand, plastic debris can be aggregated with other natural or artificial substances, ultimately leading to sedimentation or shore deposition (Wang et al., 2016).

Natural processes affecting the distribution and fate of plastics



Out of sight, out of mind?

Debris reaching the marine environment accumulates in different "storage compartments," including coastal beaches, mangroves, wetlands and deltas, the water column and the sea floor. In the water column, debris can be found floating at the surface as well as submerged in the deepest waters. Debris is also present on the seabed and in the sediment from the shallow coast to the floor of abyssal plains. In addition, marine organisms can ingest debris of various sizes, turning biota into another "storage compartment" for accumulation of debris within the marine environment.

The type and severity of the impacts of debris in any area will be strongly dependent on the abundance and composition of the debris. The proportion of the total quantity of plastic debris in respective areas, and the fluxes between them, have been subject to research and discussion for years. Even though the overall picture is still unclear, there have been noticeable advances in determining the input associated with mismanaged solid waste on land and the concentration and stocks of plastic particles in the surface layer of the open ocean.

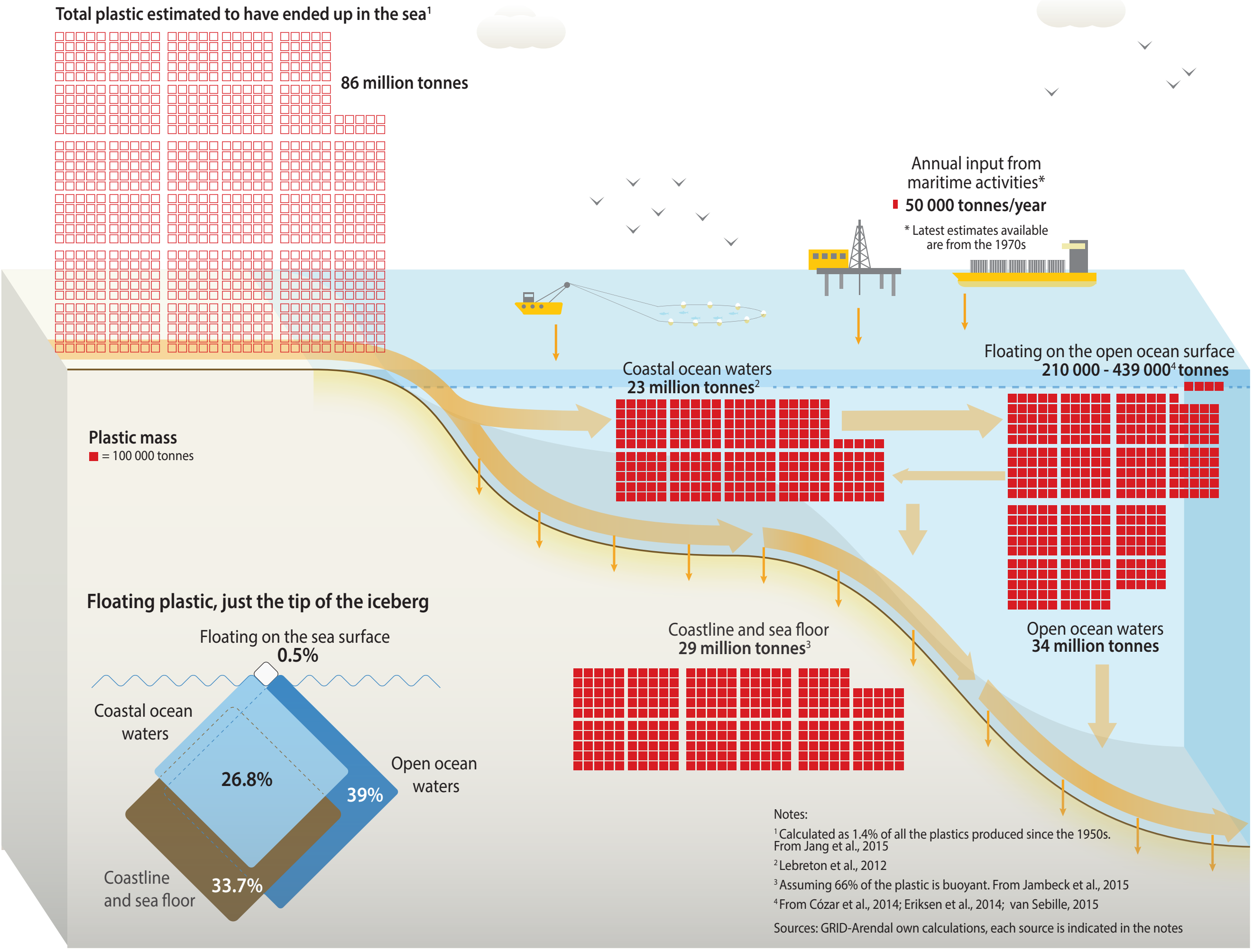
Below follows a discussion on what would be the distribution of plastic debris within the different storage compartments in the ocean. This discussion is based on the presently available estimates for influx and stocks and on assumptions on the behavior of plastic debris in the marine environment according to their density and the rate of exchange of water between the coastal and open ocean. Even if the degree of uncertainty is large for both the influx and stock estimates and for the assumptions used to discuss the fate of plastic debris, these estimates provide an indication of the potential orders of magnitude for accumulation in the different compartments and highlights the need for better understanding of the fate of plastic in the ocean.

However, attempts to quantify global influx have resulted in figures in the order of thousands to millions of tonnes per year for sea-based and land-based sources respectively. In the 1970s, the estimated input of debris from marine sources was 6.36 million tonnes of litter per year, of which 45,000 tonnes would be plastic, assuming that an average 0.7 per cent of the litter was plastic (National Academy of Sciences, 1975). Estimates of debris from land-based sources are available from 2010 and indicate an estimated 4.8 to 12.7 million tonnes entering the ocean (Jambeck et al., 2015). If these estimates are valid, they indicate that in the 1970s, an estimated 0.1 per cent of plastic produced was dumped into the sea directly from sea-based activities. By 2010, between 1.8 and 4.7 per cent of global plastic production reached the sea from land-based sources.

Due to the slow rates of plastic degradation in the marine environment (from months to hundreds of years), it can be assumed that much of the debris that leaked into the ocean after the onset of mass production in the 1950s is still there. Rough estimates of the global stock of plastic marine debris range between 86 and 150 million tonnes, assuming leakage ratios between 1.4 and 2.8 per cent (Jang et al., 2015 and Ocean Conservancy and McKinsey Center for Business and Environment, 2015 respectively).

Half of the plastic produced today is buoyant (PlasticsEurope, 2015) and research indicates that it makes up more than half of the plastic in the waste stream. Waste management data from North America indicate that about 66 per cent of plastic in the solid waste stream is buoyant. The remaining 34 percent of plastic in the solid waste stream, which includes different polymers such as PET from beverage bottles, is non-buoyant (Engler, 2012). The latter sinks because of its density and is often dragged by near-bottom currents and eventually accumulates on the seabed (van Cauwenberghe et al., 2013; Pham et al., 2014; Woodall et al., 2014). If we assume that the total plastic debris which has accumulated in the ocean since the 1950s weighs approximately 86 million tonnes (Jang et al., 2015), we can use the buoyant/sinking ratio above to calculate the amount floating on the surface and that residing on the seabed. Thus, the quantity floating equates to 57 million tonnes, leaving 29 million tonnes to sink to the sea floor. The floating component can either remain in the coastal waters or eventually be dispersed in the open ocean. It has been estimated that between 60 and 64 per cent of floating plastic discharged into the marine environment from land-based sources is exported from coastal to open ocean waters (Lebreton et al., 2012), a ratio that would indicate a minimum of 34 million tonnes of plastic floating in the open ocean.

How much plastic is estimated to be in the oceans and where it may be



Estimates of the open ocean surface stock of plastic debris have been steadily rising from 7,000–35,000 tonnes (Cózar et al., 2014) to 66,000 tonnes (Eriksen et al., 2014), and to 93,000–236,000 tonnes (van Sebille et al., 2015). The variation is mainly explained by differences in data standardization and methods used to scale up to global loads. Including floating particles larger than 200 mm, not considered in the figures above, would add a minimum of 203,000 additional tonnes to these estimates (Eriksen et al., 2014). Even using the highest of these figures, plastic debris represents only about 1 per cent of the 34 million tonnes of plastic waste estimated to be floating in the open ocean.

Several explanations are put forward to account for the mismatch of about 99 per cent between the above generic calculation of the amounts of buoyant plastic in the open ocean and the amounts so far estimated through direct measurement, extrapolation and modelling (Cózar et al., 2014; Eriksen et al., 2014; van Sebille et al., 2015). This could be due to transfer mechanisms that are hard to measure, such as shoreline deposition, decreased buoyancy due to fouling, uptake by biota and excretion through sinking faecal pellets, degradation, and high-energy oceanographic events leading to massive transportation from surface coastal areas to the deep open ocean. It has also been pointed out that the methods used so far to measure floating plastics do not capture the largest or the smallest items, thus leading to concentration underestimates.

In summary, it is very important to note that while a lot of attention has been paid to the accumulation and potential impacts of plastics on the surface of the open seas, and solutions for its clean-up, this accounts for only about 1 per cent of the plastics estimated to have been released into the ocean. The other 99 per cent has received much less attention and, even if we improve the methods for determining the distribution of plastics in open ocean waters (i.e. at the surface or through the whole water column), these calculations indicate that less than 30 per cent of plastic debris "resides" in open ocean water. The remaining nearly 70 per cent – accumulated where sensitive ecosystems and many important economic activities are found – has been overlooked. The focus needs to be broadened to include risk assessment and clean-up operations in these areas.

What are the policy responses to the problem?

Due to the varied sources, pathways and persistence of plastic debris in the marine environment, there is a myriad of environmental regulations which have a bearing on how to address this problem. These range from global generic instruments on marine environmental protection and pollution, through marine litter action plans at the regional level to specific product bans at the national or municipal level.

Within the instruments with global and regional scope there are conventions, protocols and agreements which are transposed to similar legal instruments at the regional and national level respectively. In addition, there are instruments which provide guidance and encourage regional bodies and countries to follow certain proposed actions and cooperate on marine litter issues (Chen, 2015).

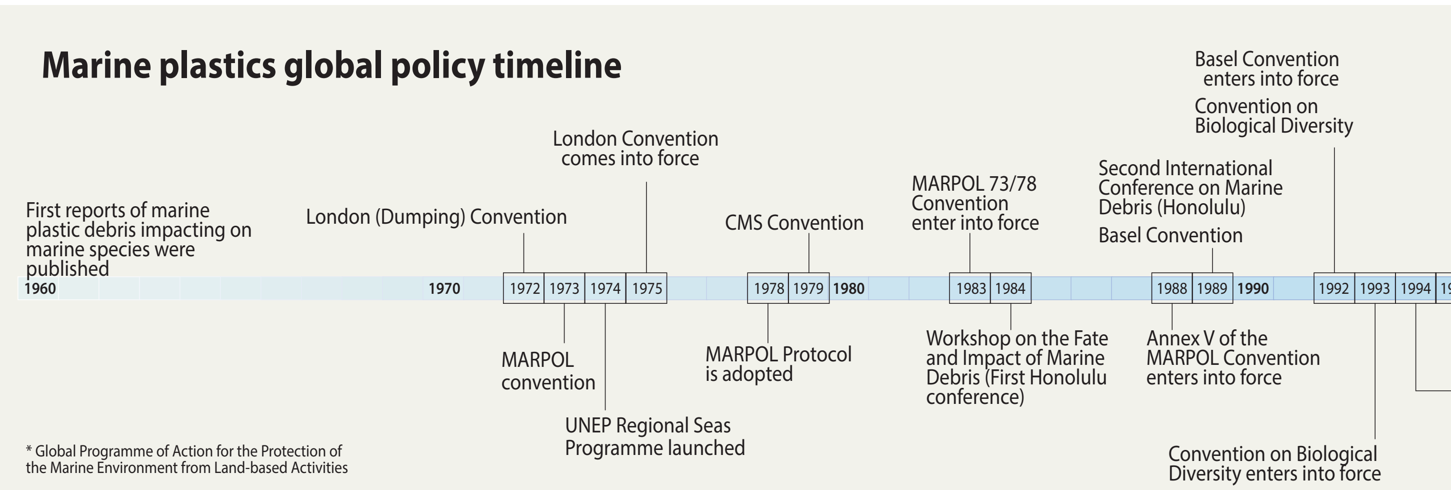
Sustainable Development Goals (SDGs)

The UN 2030 Agenda for Sustainable Development (UN General Assembly Resolution 70/1) adopted in September 2015 provides an overarching framework to place other international, regional, national and local initiatives in context. Four out of the 17 SDGs (6, 11, 12 and 14) have associated targets particularly relevant to marine plastic pollution. These targets focus on untreated wastewater (6.3), municipal and other waste management (11.6), environmentally sound management of chemicals and all wastes throughout their life cycle (12.4), and waste generation reduction through prevention, reduction, recycling and reuse (12.5). Others include prevention and reduction of marine pollution, in particular from land-based activities, including marine debris (14.1), sustainable management and protection of marine and coastal ecosystems and action for their restoration (14.2), and conservation and sustainable use of oceans and their resources through the United Nations Convention on the Law of the Sea (UNCLOS) (14.c) (UNEP, 2016a).

Also focusing on sustainable development but specifically aimed at Small Island Developing States (SIDS), the SIDS Accelerated Modalities of Action (SAMOA) Pathway was adopted in September 2014, and provides an overarching framework for initiatives. Article 58 on oceans and seas and article 71 on management of chemicals and waste, including hazardous waste, make specific reference to addressing marine debris and strengthening mechanisms for waste management including marine plastic litter.

UNCLOS

The United Nations Convention on the Law of the Sea (UNCLOS), in force since 1994 with 167 parties including the European Union, constitutes the global legally binding instrument regulating activities carried out in oceans and seas. Part XII is dedicated to the protection and preservation of the marine environment and requires states to take measures to prevent, reduce and control pollution of the marine environment from any source. It includes provisions on land-based sources of pollution, pollution from vessels, seabed activities, and dumping



and pollution from or through the atmosphere applicable in the context of marine litter (UNEP, 2016a).

Every year the UN General Assembly discusses the oceans and the Law of the Sea. The annual resolution of 2005 included provisions related to marine debris. In 2014 a UN General Assembly resolution included the decision to devote the meeting of the Open-ended Informal Consultative Process on Oceans and the Law of the Sea, to be held in June 2016, to the topic "Marine debris, plastics and microplastics" (UNEP, 2016a).

Also under UNCLOS, the United Nations Fish Stocks Agreement, in force since 2001 and with 83 parties to date, includes references to reducing the impact of fishing gear, gear marking and retrieval of abandoned, lost or otherwise discarded fishing gear (ALDFG). Derelict fishing gear is, in certain parts of the ocean, one of the major contributors to marine litter and has far-reaching ecological and socioeconomic impacts.

MARPOL 73/78

The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) has been in force since 1983. Annexes IV and V deal respectively with pollution from ships by sewage and by garbage. Annex V, in force since 1998 and revised in 2013, binds 149 parties and covers 98 per cent of the world tonnage (IMO, 2016). It includes a complete ban on disposal into the sea of all forms of plastic. It also includes provisions on the obligation to provide a Garbage Record Book for ships above 400 gross tonnage or certified to carry more than 15 persons, and on the availability of adequate port reception facilities. In relation to this, in 2006 the International Maritime Organization approved an action plan on tackling the inadequacy of port reception facilities to contribute to the effective implementation of MARPOL and to promote environmental consciousness among administrations and the shipping industry (Chen, 2015). Provisions in Annex IV allow for the discharge of sewage with different degrees of treatment at different distances from the coast, allowing for the potential entry of small plastic debris or microplastics in to the sea.

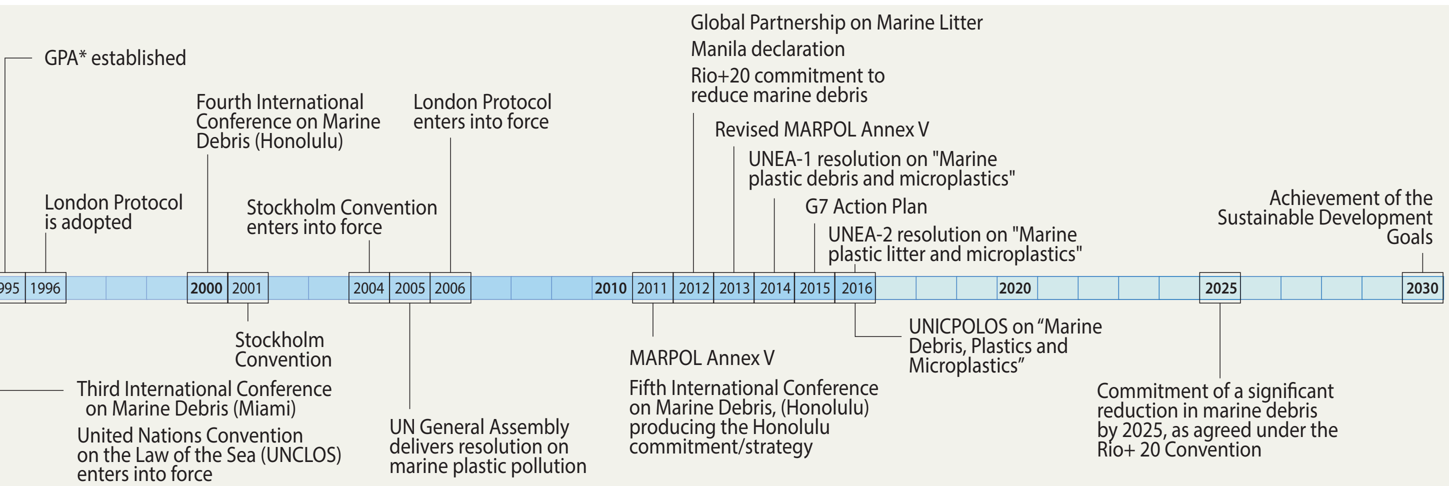
London Convention

The London Convention, in force since 1975, and the more restrictive London Protocol, in force since 2006, provide effective control aimed at all sources of marine pollution and take practical steps to prevent pollution by dumping of waste at sea. Under these instruments, disposal at sea of persistent plastic and other synthetic materials (such as netting and ropes) is prohibited. Recently its Secretariat commissioned a review to stimulate further discussion on marine litter derived from waste streams dumped at sea, under the London Convention and Protocol. Sewage sludge and dredged material were considered most likely to contain plastic (UNEP, 2016a).

In addition to the above conventions that address regulation of activities at sea, there are four other multilateral environmental agreements related to nature conservation and biodiversity (the Convention on Migratory Species and Convention on Biological Diversity) and to hazardous substances (the Basel Convention and Stockholm Convention), the provisions of which have implications for reducing either the impacts or the sources of marine plastic debris and microplastics. In 2011, the Parties of the Convention on Migratory Species adopted a resolution on marine debris.

Global Programme of Action (GPA)

When it comes to regulation of activities on land that have direct consequences on the flow of pollutants into the ocean, the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) is the only existing global intergovernmental mechanism directly addressing the connection between terrestrial, freshwater, coastal and marine ecosystems. Marine litter is a priority pollution source category under



the GPA. The regulatory power of the GPA is limited but it aims to be a source of conceptual and practical guidance for national and/or regional authorities in devising and implementing sustained action to prevent, reduce, control and/or eliminate marine degradation from land-based activities. UNEP provides the Secretariat for the GPA.

Other global or multinational initiatives

The Honolulu Strategy formulated in 2011 is the only specific framework for a comprehensive and global effort to reduce the ecological, human health, and economic impacts of marine debris globally (UNEP and NOAA, 2012). It is focused on preventing the input and impact of marine debris from both land- and sea-based sources and on the removal of already accumulated debris. It aims to provide a common frame of reference for collaboration and sharing of best practices for action plans, programmes and projects. It is also envisaged as a monitoring tool to measure progress in combating marine debris.

Under the GPA, the Global Partnership on Marine Litter (GPML) was launched in June 2012. The GPML, which builds on the Honolulu Strategy, is a voluntary multi-stakeholder coordination mechanism in which all partners agree to work together towards the reduction and management of marine litter.

During their summit in 2015, the Group of 7 (G7 – Canada, France, Germany, Italy, Japan, the United Kingdom, the United States and the European Union) committed to the Action Plan to Combat Marine Litter, which includes priority actions to address land-based and sea-based sources, priority removal actions and priority actions on education, research and outreach.

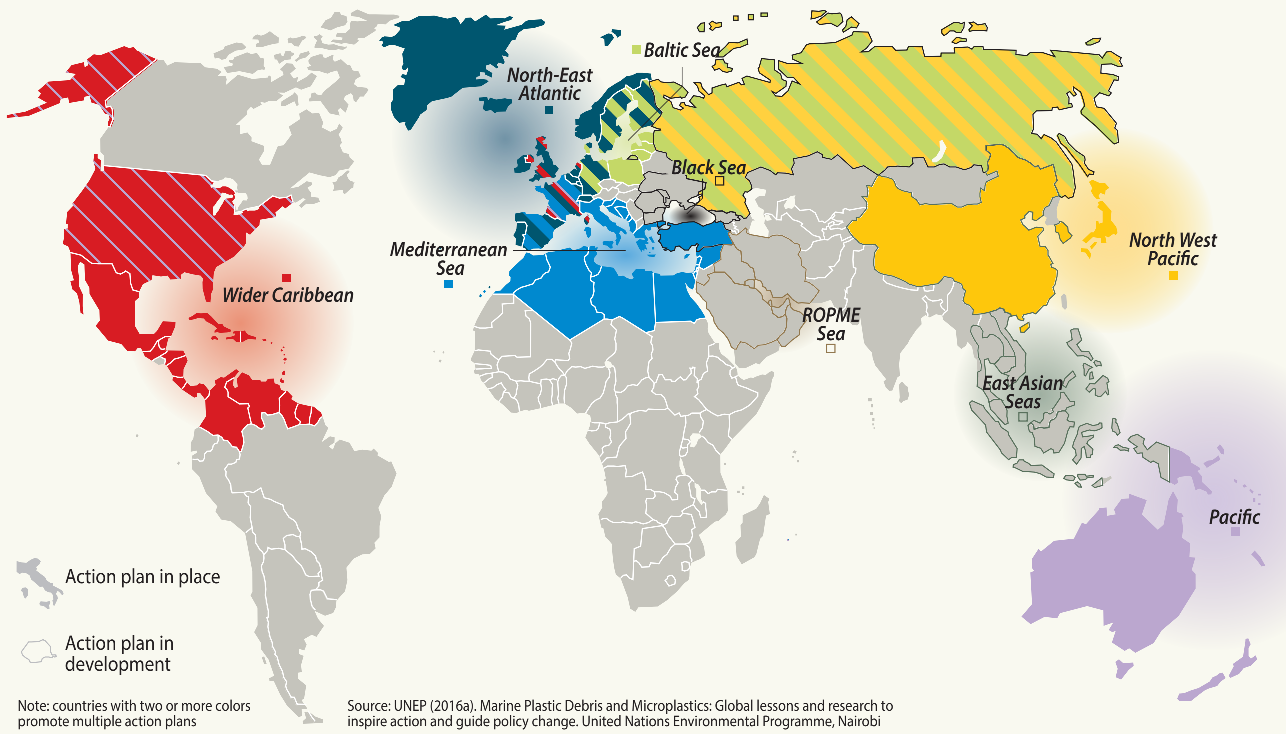
The UNEA resolutions

The first session of the United Nations Environment Assembly (UNEA) in 2014 adopted resolution 1/6 on marine plastic debris and microplastics, which requested UNEP to present a study on the topic to the second session of UNEA. A new more action oriented resolution 2/11 on marine litter was adopted in May 2016 which for example called for establishment of public-private partnerships, development of campaigns for awareness-raising, prevention and clean-up and encouraged product manufacturers to consider the lifecycle environmental impacts of products containing microbeads and compostable polymers. It also requested UNEP to assess the effectiveness of relevant international, regional and sub-regional governance strategies and approaches to combat marine plastic litter and microplastics.

Regional seas bodies

Regional Seas Conventions and Action Plans (RSCAPs) play a critical role in encouraging cooperation and coordination among countries sharing a common resource. There are 18 Regional Seas Conventions and Action Plans covering more than 143 countries (UNEP, 2016a). Of these, the following 13 were established under the auspices of UNEP (with those currently administered by UNEP in italics): Black Sea, *Caspian, Wider Caribbean,*

Regional action plans on marine litter



Note: countries with two or more colors promote multiple action plans

Source: UNEP (2016a). Marine Plastic Debris and Microplastics: Global lessons and research to inspire action and guide policy change. United Nations Environmental Programme, Nairobi

East Asian Seas, Eastern Africa, South Asian Seas, ROPME Sea Area, *Mediterranean*, North-East Pacific, *North-West Pacific*, Red Sea and Gulf of Aden, South-East Pacific, Pacific, and *Western Africa*. The four other Regional Seas programmes cover the Antarctic, Arctic, Baltic Sea and North-East Atlantic regions. Most of these programmes function through an Action Plan, underpinned in most cases by a regional sea convention and its associated protocols, or by other legal frameworks on different aspects of marine environmental protection.

The Regional Seas Conventions and Action Plans are instrumental in supporting the implementation of the GPA at regional levels and have developed, or are in the process of developing, regional sea action plans on marine litter. The regional plans take into account the environmental, social and economic situation of each regional sea and they vary in the detail and extent of actions recommended to the states (UNEP, 2016a). While, for example, in the Mediterranean the strategic framework includes legally binding measures, the regional action plans for the Baltic and North Atlantic are built around a set of fundamental principles and, similar to the G7 Action Plan, a series of regional and national actions to address land-based and sea-based sources, priority removal actions and priority actions on education, research and outreach. Otherwise in the Pacific marine debris has been identified as a priority area in the broader Pacific Regional Waste and Pollution Management Strategy 2015–2016.

Regional and national policies

The European Union, through its member states, has become a leading voice for defining marine environmental policy in the European Seas (Baltic, Black Sea, Mediterranean and North Atlantic). Through the regional seas, its influence reaches beyond the borders of the European Union and the waters of its member states. It has adopted a number of measures on waste management, packaging and environmental protection that are relevant to the reduction of marine plastic debris and are applicable to the 28 member states of the EU. Some of the regulations are devised within the EU, such as the Marine Strategy Framework Directive, an integral policy instrument for the protection of the marine environment for the European Community. The Directive, adopted in 2008, aims at achieving Good Environmental Status by 2020 through 11 areas, one of which is devoted to marine litter, assessed through a series of indicators and targets. The EU has also developed other instruments relevant to marine litter, such as the EU Port Reception Facility Directive in force since 2002, aimed at transposing MARPOL 73/78, and land-based waste management initiatives such as the Packaging Waste Directive, the Waste Framework Directive, the Landfill Directive and the Urban Waste Water Directive (Chen, 2015). More specifically, the European Strategy on Plastic Waste in the Environment looked at aspects of plastic production, use, waste management, recycling and resource efficiency, in order to facilitate the development of more effective waste management guidelines and legislation (UNEP, 2016a).

Many national and local instruments have been developed that are relevant to marine litter. Of course the diversity of instruments increases dramatically where they have national or local scope, due to the fact that these instruments are tailored to the specific environmental and socioeconomic characteristics or the geographical area covered by the regulation. As is the case for regional instruments, some states (e.g. Japan, Korea, Singapore and the Netherlands) have developed overarching national legislation and policies to address marine litter, but such legislation remains uncommon globally. Up until now the more common practice has been to adopt overarching instruments under international or regional cooperation frameworks. Where states have overarching legislation, it often serves as a coordinating and planning mechanism, helping to integrate the existing instruments and to design priority actions.

In addition to, or in place of, overarching approaches there are many instruments addressing specific aspects of marine litter. These can be broadly regarded as upstream instruments, such as prohibiting and disincentivizing the manufacture and use of materials and products susceptible to becoming marine plastic debris or microplastics. There are also downstream instruments which address the adequate disposal of waste on land or at sea.

Upstream manufacturing instruments address, at various levels, the production of plastic pellets (California), plastic bags (Bangladesh, South Africa, China and Rwanda), polystyrene foam (Haiti and Vanuatu) and microbeads (Canada, USA federal government and nine states). Regulations using extended producer responsibility in the manufacture of plastic and plastic items are also in place in Canada, Japan, Australia and New Zealand. The most common upstream instruments in retail use target plastic bags including bans, regulation of bag thickness, taxes on end-user bags or a combination of these. Bans are also in place locally on single use food and drink related plastic products (Tamil Nadu in India and Bangladesh) and on those using polystyrene foam (New York City and several cities in California) (UNEP, 2016b).

Downstream instruments on land take the form of mandatory recycling and separation, the collection of waste and disposal in adequately located and managed facilities and landfills, incineration and planning, and disaster preparedness, which are in place in many countries (UNEP, 2016b).

Better (and cheaper) to be tidy than to have to tidy up

Avoiding environmental pollution is a better and cheaper option than cleaning up or mitigating the impact of pollution. There are many ways to tackle the problem of marine plastic debris and microplastics – from preventive upstream measures, through mitigation, to downstream removal.

Upstream preventive measures are preferable to downstream removal as they address marine litter at its source by reducing the generation of waste that could become marine litter. These include improved product design, substitution or reuse of materials and more efficient manufacturing. Mitigation through improved waste management, including recycling, can help prevent waste from reaching the marine environment. Finally, downstream litter removal tackles the problem where the impacts are being felt in the marine environment. Beach cleaning or fishing for litter are two examples of actions that can have an immediate, positive effect (UNEP, 2016c).

There are also behaviour change initiatives which seek to influence people in a way that helps to reduce marine litter. Behaviour change initiatives are cross-cutting and address the development and implementation of measures for prevention, mitigation and removal (Chen, 2015).

The choice is broad and the different types of measures within the categories named above include awareness raising (such as campaigns promoting smartphone apps), research and development (for product innovation), and policy and regulation (bans and application of extended producer responsibility). Others include direct investments (government spending on waste management infrastructures), market-based instruments (deposit-refund schemes or product charges) and clean-up measures (UNEP, 2016c). These measures are currently being implemented but also look to the future. Attention should be placed in ensuring that future interventions are environmentally sound and risk based. In addition, the various measures will be most successful if gender and other demographic dimensions are taken into account. This is because the activities generating plastic debris, the sectors of society that are affected by potential impacts, and the behaviour patterns are all gender-differentiated and depend on income, age and other social factors.

Awareness raising

Awareness raising activities among distributors/retailers and consumers can help to avoid the generation of marine litter, for example by providing purchasing options to reduce consumption of plastic bags and cosmetic products containing microbeads, and reinforcing the benefits of proper waste selection and disposal. Awareness raising campaigns should be diverse and focus on the costs of inaction – and the costs and the benefits of action. Campaigns should focus on business and citizens and account for gender, race, age and class. They should use different channels, including formal and informal education, with a particular emphasis on children (beach clean-ups being a good tool). There is also a need for traditional and social media, as well as attractive tools such as videos, music, art, and smartphone apps for community science.

Research and innovation

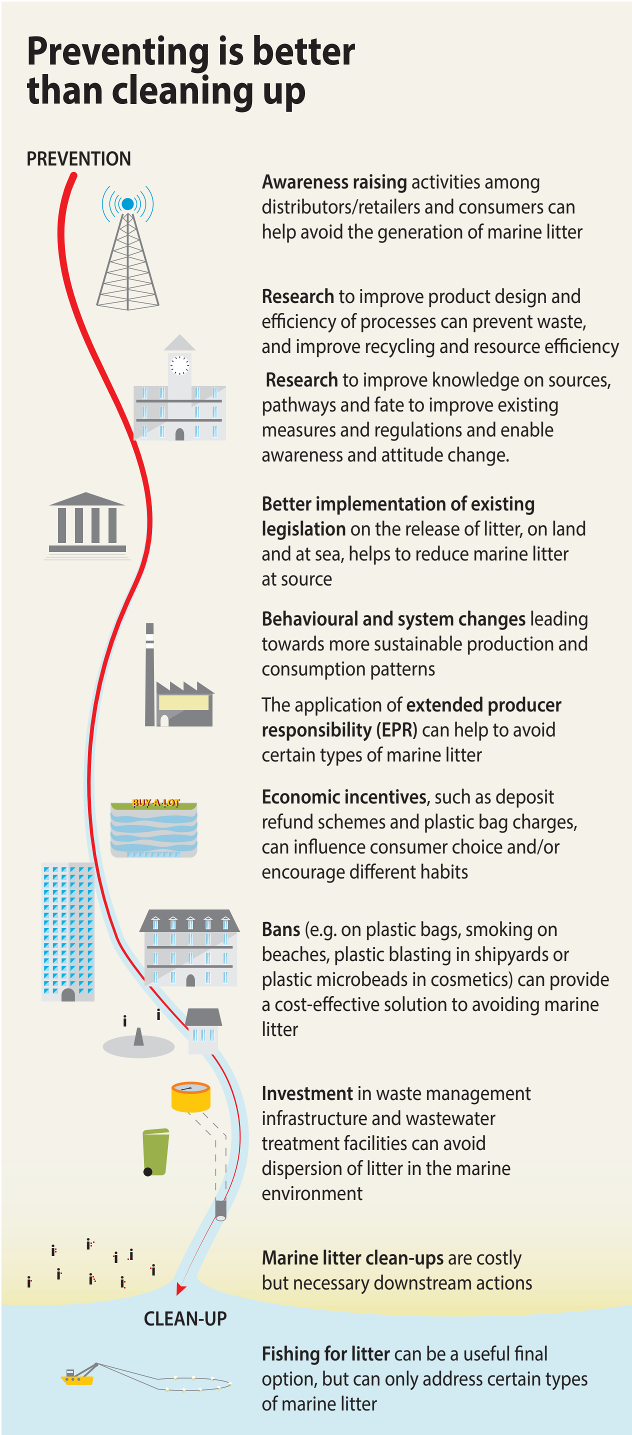
The research effort to address marine plastic debris and microplastics needs to be twofold. First, further research is needed to better understand drivers, sources, status and impacts, to enable the development and improvement of existing legislation, policies and targeted tools and measures (research-based policy and action). These research efforts should look into the costs of inaction versus the costs and benefits of action, to inform decision-making and identify which instruments are likely to be effective and efficient, work with other policies, and offer added value.

Second, research and innovation is also required to improve product design and processes to prevent waste, improve recycling and increase resource efficiency. Research into design options, in particular for plastic and plastic products, will facilitate reuse, repair, remanufacture and recycling and support a transition to a more sustainable economy.

Policy implementation

Thorough implementation of existing legislation and policies on the release of litter, on land and at sea, helps

to reduce marine debris at the source. There is already a wealth of environmental regulatory instruments addressing release of litter both on land and at sea which, if implemented to their full extent, would have a noticeable effect on the amount of marine plastic debris released into the ocean.



Extended producer responsibility

The application of extended producer responsibility (EPR) can help to avoid certain types of marine litter, including some that is particularly prevalent such as single-use packaging items. Making producers financially and/or logistically responsible for their products at the end-of-life stage encourages the development of take-back and collection.

Economic incentives

Deposit-refund schemes and plastic bag charges can influence consumer choice by influencing which products to buy. They can also encourage different habits such as returning bottles or carrying multi-use bags. In this way these incentives can act as an effective upstream measure. Incentives ensure awareness of the fact that plastic has a price – at the beginning and the end of its life – and it is therefore more widely recognised as a valuable resource. This reduces consumption and waste and increases recycling, as well as supporting the transition to a circular economy.

Bans

Bans on plastic bags, smoking on beaches, plastic blasting in shipyards or plastic microbeads in cosmetics can provide a cost-effective solution to avoiding marine litter, although feasibility will depend on various factors including the availability of substitutes, competitiveness concerns and political will.

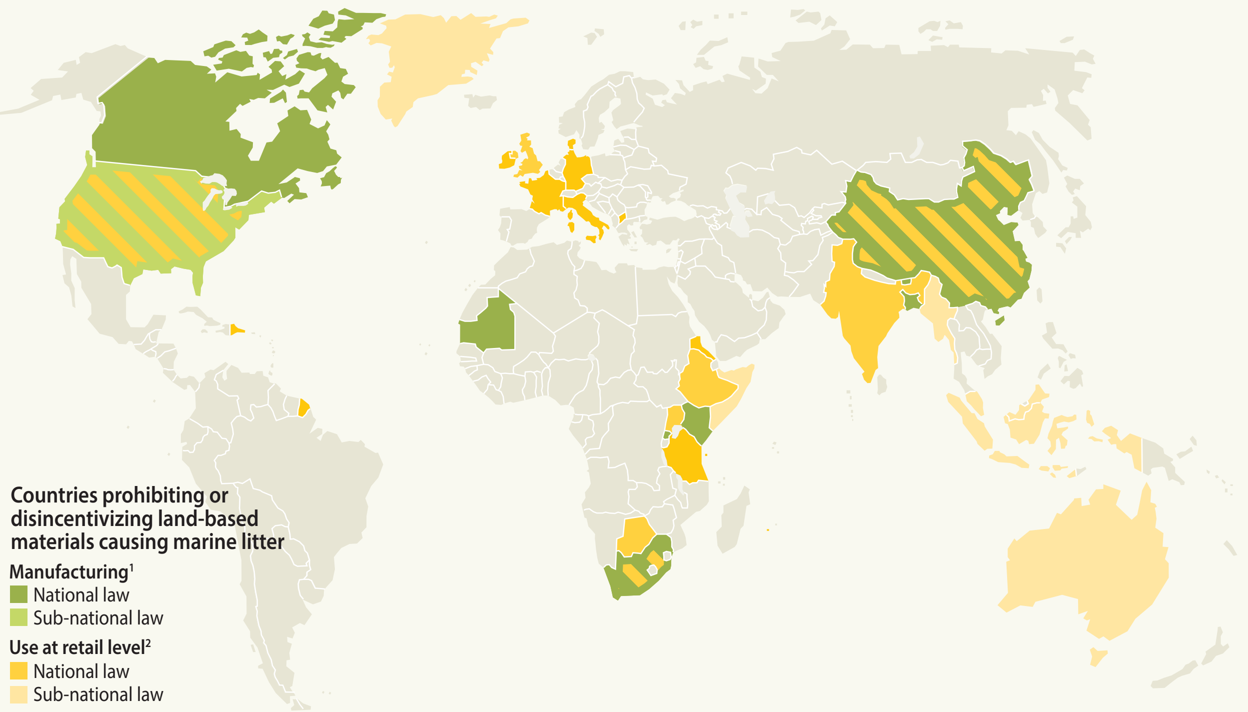
Investment in waste management and wastewater treatment infrastructure

Investment in waste management infrastructure and wastewater treatment facilities can avoid dispersion of litter in the marine environment. This can include perimeter netting at landfills to catch windblown waste, improved beach and port waste infrastructure, and investments in wastewater treatment plants to provide litter traps and filters to capture microfibres (although this does not address items transported through storm drains). Investment in waste collection and management in coastal areas or near rivers, and particularly in areas where infrastructure is inadequate or absent, would help to contain the transportation of litter to the ocean.

Clean-ups and fishing for litter

Environmentally sound and risk-based clean-ups are costly but necessary downstream actions (at least until marine

What countries are doing to combat litter



[1] Includes one or more of the following categories: nurdles or pre-production plastic, plastic bags and microbeads in personal care products

[2] Includes one or more of the following categories: plastic bag laws; laws governing the thickness of plastic bags; bans on stirrers,utensils and cups; taxes or levies on plastic bags; bans on so-called "biodegradable" plastics; bans on polystyrene, mandating "re-usable" products such as beverage containers and shopping bags; cigarette bans on beaches

Source: UNEP Marine Litter Legislation: A Toolkit for Policymakers, document in preparation, 2016; The Independent, The Guardian, National Geographic press review

litter is tackled closer to its source). Engaging volunteers in clean-up activities can help reduce costs (although the time of volunteers also has an economic value), contribute to citizen science and improve awareness.

Fishing for litter can also be a useful final option, but can only address certain types of litter. This could be combined with economic incentives to encourage action, such as payments to fishermen for the litter they collect.

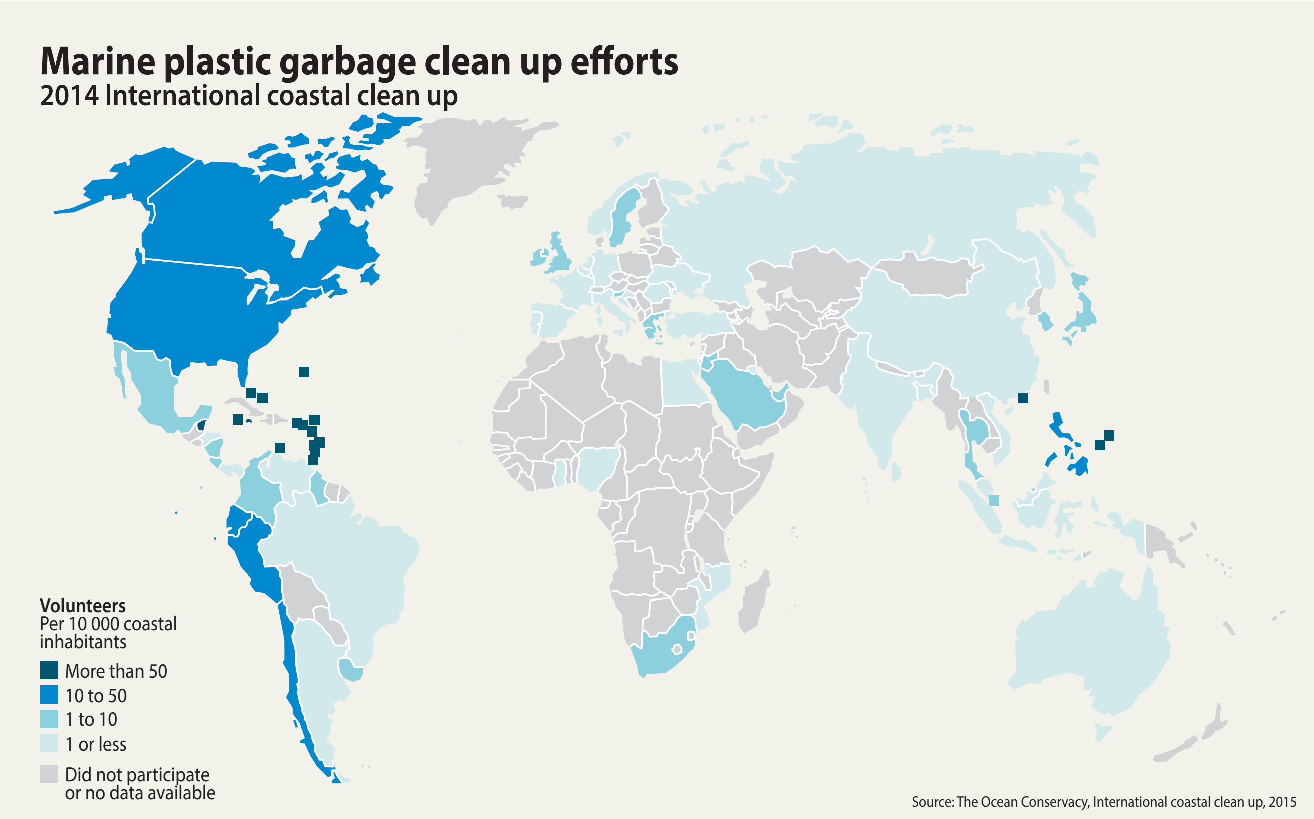
The fact that marine debris and microplastics constitute a complex environmental challenge also poses an opportunity when it comes to tackling it. Before choosing an instrument or a package of instruments, it is crucial to assess whether it will work within a country's legislative, institutional and cultural context. This assessment will help in determining the likelihood of implementation, who will be involved, what the costs will be, who they will fall to, the expected effectiveness and impacts over what timescale, the potential perverse incentives that may undermine effectiveness or efficiency, and the environmental, social and economic benefits and costs of action.

The cost of action

The costs of action will vary depending on where in the value chain and on what waste the measures are focused, which sectors and products they target, and the location and scale of the marine litter being addressed. While there are still data gaps it is expected that the cost of action is significantly less than the cost of inaction.

It is in the interests of many economic sectors to find strategies to reduce marine litter because this can help to reduce the cost to them. The benefits of action are not just about avoiding the problems arising from inaction, but also about new opportunities – for the economy and society.

In some cases, significant value can be generated from recycling marine litter into new products or "upcycling" (UNEP, 2016c). The Kenyan-based Ocean Sole creates 220 different products from recovered flip-flops and sells up to 500,000 dollarsworth of products each year. Through the Net-Works programme, the world's largest carpet tile producer, Interface, and its material partner Aquafil, reprocess discarded and abandoned fishing nets from the Philippines into carpet products which are used in buildings around the world. Through its Net+Positiva programme, Bureo turns collected fishing nets into skateboards that retail at 149 dollars and sunglasses that retail at 129 dollars. Over 3,000 skateboards have been sold to date. Items in the RAW for the Oceans fashion range by G-Star Raw and Bionic Yarn, which contain yarn made from PET bottles recovered from the oceans, retail for as much as 300 dollars.



Generally, however, the value of marine plastic for recycling is less than that of the plastic before it became contaminated or partly degraded in the marine environment. This is because plastic that has spent time in the oceans may absorb chemical or biological materials, or may partially degrade to the point that it can no longer be used in standard recycling processes since it would reduce the quality of the recycled material.

Dealing with marine litter can benefit communities through awareness raising, education and paid employment in projects such as litter picking or upcycling, which can also help to develop marketable skills. It can also support long-term livelihoods in fisheries or tourism and promote well-being linked to recreation. Social cohesion can be fostered through revenue-raising for litter projects, or through a wider sense of ownership of, and responsibility for, a clean environment. Efforts in these domains need to be gender-sensitive, recognizing that men and women participate in fishing and tourism livelihoods differently, and recognizing that women and men often participate differently in community improvement activities.

Big questions that remain unanswered

There are still many important questions left unanswered on the impact of marine debris and plastic contamination on human health, the environment, food security and socioeconomic systems. Moreover, there is a growing sense that we have a collective moral responsibility to prevent the oceans from becoming more polluted. Both decision-makers and researchers benefit from identifying knowledge gaps, to support the fulfilment of societal goals and to pinpoint future areas of research and potential applications.

What follows is a summary of the key research needs (UNEP, 2016a) to guide governments and researchers in their quest to ensure environmental sustainability for all, especially – but not only – in the context of Sustainable Development Goal 14 to "Conserve and sustainably use the oceans, seas and marine resources" and target marine litter. In addition to further research, it will be necessary to secure funding and greater international collaboration to achieve these goals. It should be noted that any interventions should be environmentally sound and risk based.

Governance

Current legal frameworks have not been sufficient to stop plastic from entering the ocean, mainly because they either do not address all the key sources and entry points or there is a lack of implementation and enforcement of existing legislation. Policies and strategies are not yet gender-responsive nor do they sufficiently address other demographic factors.

The effectiveness of current relevant international and regional governance mechanisms, including their implementation and enforcement, needs to be assessed. Gaps need to be identified and new governance mechanisms need to be explored.

Properties of different plastics

The release of chemicals that are added to plastics to achieve a range of desirable properties (such as UV resistance, increased plasticity and flame retardancy) can have profound effects on biological systems, in particular on the endocrine system. Further research is required to minimize the use of, and to determine the least harmful, additive chemicals. Research is also needed to determine and minimize the degree to which these pollutants can seep from plastic debris into the water column and organisms that eat the debris. It is also necessary to determine the exact source of these pollutants because they can come from sources other than plastic debris.

Sources and pathways

The quantities, relative importance, spatial distribution and gendered and other demographic aspects of different land- and sea-based sources of macroplastics need to be monitored and assessed. The same goes for different sources of primary and secondary microplastics and their entry points into the ocean.

The factors and risks contributing to their release need to be investigated, including the relative importance of catastrophic events such as storms and floods. Analysis needs to be carried out on river and atmospheric transport, wastewater and the most vulnerable coastlines and communities.

Distribution and fate of plastics

We need to draw on expertise from polymer and materials science in order to gain a better understanding of the behaviour of the main types of plastics in the marine environment, including conditions controlling the rates of weathering, fragmentation and biodegradation.

Current surface circulation models provide a reasonable representation of the transport of floating plastics on a global scale, on the basis of observed distributions (Ericksen et al., 2015, as cited in UNEP, 2016a). However, many plastics are denser than water and therefore will be expected to eventually sink. There is a lack of data on both sub-surface distribution of plastics in the water column and seabed, and on the rate and nature of vertical and horizontal transport processes. From a management perspective there is a need to develop harmonized monitoring techniques and encourage citizen science to improve data collection and quality, and to develop models to better support reduction measures.

Impacts

There is an urgent need to quantify the effects of macro- and microplastics on marine organisms and to further investigate effective prevention techniques. Besides the impact on human health through consumption of fish, which is addressed in a separate section below, there are some other research questions in relation to microplastics. These include the need to better understand the relationship between pathogens and microplastics. Other questions include the role of microbes in facilitating the fouling of microplastics by organisms, the ingestion of microplastic by organisms, and the potential transformation of toxins.

There are a number of knowledge gaps that make it difficult to take the social dimension into better account in discussions about reducing the impact of marine plastic litter. Differences in consumer perception and behaviour of men, women and young people need to be studied to improve targeted measures and management issues. Why do some people take responsibility and others not? What drives behaviour change? These are just two of many questions that need to be answered.

Risk assessment

Specific research is needed to improve methodologies for measuring the loss of ecosystem services. Risk assessments and cost-benefit analyses need to be performed, and methods to effectively communicate the results need to be developed, in the areas of food security and safety, biodiversity, human health, social and economic impacts.

Economic dimensions

There is a need for improved understanding of the cost and benefits of action in order to highlight cost-effective solutions. The inefficiency of letting plastic become waste needs to be assessed and the economic implications of reducing the use of plastics and recycling plastic waste need to be estimated.

Fisheries and aquaculture

There are research needs concerning the fisheries and aquaculture sectors, with respect to sources, impacts and potential solutions and the role of women in fisheries.

Abandoned fishing gear is, in certain parts of the ocean, one of the major contributors to marine litter and has far-reaching ecological and socioeconomic impacts. Studies have shown that fish and other marine life eat plastic. Plastics can cause irritation or damage to the digestive system. If plastics are retained in the gut instead of passing through, fish can feel full (of plastic not food) and this can lead to malnutrition or starvation.

Primary and secondary microplastics are also ingested and enter the food chain. Given the relatively recent emergence of this research, there are few consistent and validated methodologies in place for the quantification and qualification of plastic particles from selected media (sediment, biota and water column). Above all, there is still insufficient study into the impacts and potentially harmful effects of micro- and nano-particles on organisms and ecosystems. Of major importance are the mechanisms by which microplastics are taken up and move up the trophic chain, where they may be consumed by humans, and the associated risks to human health. Special attention needs to be paid to the different effects this might cause in women, men and young children.

Conclusions

Plastic debris and microplastics are by far the main components of marine litter and are omnipresent in the world's oceans – from remote shorelines to the deep ocean, from the poles to the equator. The quantity of plastic observed in coastal waters off densely populated regions and in the mid-ocean gyres, despite high concentrations, represents only a fraction of the total amount in the marine environment. In addition, many types of plastic waste are denser than water and will sink to the sea floor. Surface accumulations in mid-ocean subtropical gyres are just the tip of the iceberg. While uncertainties remain, it is estimated that open ocean floating plastic accounts for less than 1 per cent of the total that has reached the oceans since it began to be produced.

Production of single-use, throw-away plastic products has increased exponentially since the 1950s. At the same time, plastics are designed to be durable and it is precisely this characteristic, combined with an unwillingness or inability to manage waste effectively, that has created a global issue. It is a complex social, economic and environmental problem which knows no boundaries. It threatens entire marine ecosystems, has enormous economic consequences and affects the livelihoods of millions of people.

The cause is human activity – on the land and in the seas. All sectors and individuals contribute to this pollution – from poorly controlled waste sites, illegal dumping and mishandled waste on land to floating ropes, nets, floats and other debris from fishing, merchant shipping, oil rigs, cruise ships and other sources.

Larger "macroplastics" harm marine life when animals and fish become entangled or eat them. However, more research is needed to determine impacts on population levels which can further affect endangered species, sensitive habitats and ecosystems. All of these have tangible and measurable socioeconomic consequences for fisheries, shipping and tourism.

Out of sight but not out of mind

Microplastics measure less than 5 mm in diameter and are either manufactured for industrial or domestic purposes ("primary" microplastics such as microbeads in toothpaste) or are a result of weathering and fragmentation of larger material ("secondary" microplastics). Weathering and fragmentation is assisted by exposure to UV radiation and oxygen at or close to the water surface. However, at lower levels the lack of light slows this process so that it takes a long time for even "biodegradable" plastics to break down.

There is a major gap in our knowledge about the actual quantities of plastic debris and microplastics and the proportion coming from from different sources. A further challenge is that we cannot see a large part of the litter because it lies below the surface. Even more worryingly, we don't know whether it is affecting the trophic chain; the potential for bioaccumulation in certain species; what chemicals are released into the marine environment when plastic waste degrades; the impact on food safety or the potential connections to climate change.

The fact that so much is out of sight explains why there are no reliable estimates of the total quantity of plastic in the ocean and why research on its effects on marine life and human consumption is still in its infancy. However, there is sufficient evidence that marine plastics and microplastics are having an unacceptable effect. Immediate action based on available knowledge needs to go hand in hand with improved and adaptive management and governance approaches that will evolve as more is learned.

What needs to happen now?

Prevention is key – Reduce the amounts of single-use plastics, phase out non-recoverable plastics, promote redesign of plastic products to extend their life-span and facilitate recovery and recycling once used – these are essential long-term solutions. With regard to short-term solutions, improved collection and management of wastewater and solid waste offers the most immediate short-term solution to reducing the flow of plastic into the marine environment, especially in developing economies.

New Approaches – While further research is needed to gain a better understanding of the source, transport, fate and effects of marine litter, we know enough now to design and implement science-based measures to deal with the problem. Adaptive management and policy will be instrumental in incorporating the wealth of knowledge that is continuously being generated on marine plastic debris and microplastics.

Share knowledge and expertise – New awareness raising activities need to be developed and we need to take a more multi-disciplined approach that will encourage public-private partnerships and citizen-led movements to slow down or reverse the further degradation of our marine and coastal environment.

Implement existing regulatory instruments – Full implementation of regulations and an assessment of their effectiveness will show that there is progress to be made. It will also enable assessment of how to better integrate and improve these instruments.

Behaviour change – Besides improved governance at all levels, long-term solutions should focus on behavioural and system changes such as more sustainable production and consumption patterns.

Take action – Marine litter mitigation activities such as beach and shoreline clean-ups should be prioritized in areas where action will lead to the recovery of ecosystems – and substantially increase awareness about the problem.

One size does not fit all – By acknowledging factors such as gender, demographics, individual motivations and different perceptions of risk and responsibility, the cost of action can be reduced and it can be made more sustainable.

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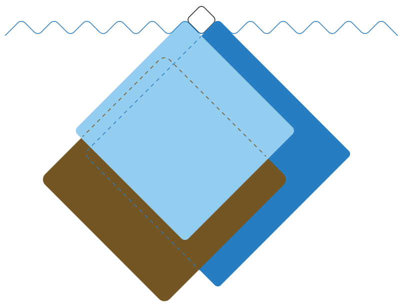
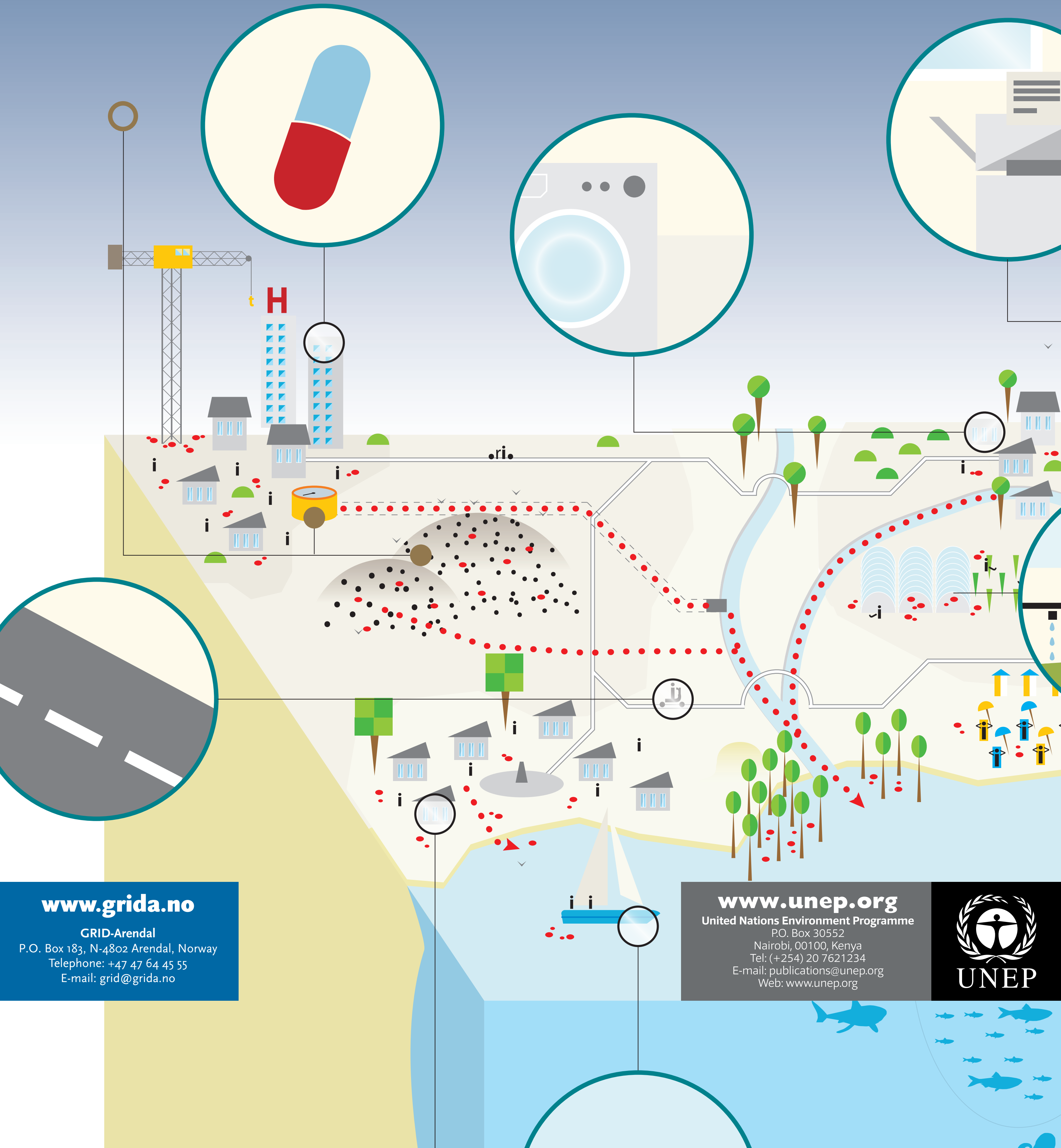


Marine litter is human-created waste that has been discharged into the coastal or marine environment. Litter sources are located on land, along the coastline or at sea and travel to the ocean through many different pathways. In the marine environment litter is transported for long distances and reaches all habitats – from the surf zone all the way to remote areas such as the mid-oceanic gyres and the deep sea floor below. Like other pollutants marine litter affects the habitats, functions and organisms of the ecosystems where it accumulates and threatens the services they deliver.



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