Marine Plastic Pollution – Sources, Sinks, and Impacts on Cetaceans

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"I am seriously worried that not enough action is being taken to prevent plastic pollution from entering the oceans and having a negative impact on cetaceans."
Silvia Frey

Introduction

Plastic has become almost indispensable in our daily life. However, this dependency and the associated vast amounts of produced and casually discarded plastics combine to create a pervasive occurrence of these persistent synthetic polymers in the marine environment, where they account for up to 80% of all marine litter (Derraik, 2002). Today, plastic debris affects every ocean and coastline in the world, from the Antarctic to the Arctic, from the water surface to the deep sea, and poses a serious threat to marine life (Galgani *et al.*, 2015; Law, 2017; Barboza *et al*., 2019).

The first scientific evidence about marine plastic pollution was published more than 40 years ago with a significant increase of more systematic and in-depth studies occurring in recent years (Ryan, 2015; Law, 2017). During the last decade, media attention on the topic has also increased considerably, whereas the need for measures to address marine debris has been recognised at various levels for some time (Law, 2017; Barboza *et al.*, 2019). For example, at the international and regional level relevant initiatives have been undertaken by the International Convention for the Prevention of Pollution from Ships (MARPOL)[1], the Honolulu Strategy (UNEP and NOAA, 2016), the International Whaling Commission (IWC) (IWC, 2014), the United Nations Environment Assembly (UNEA-2) (UNEP, 2016), the Mediterranean Regional Plan on Marine Litter[2], and the European Union (EU) Marine Strategy Framework Directive (2008/56/EC)[3] besides national legal actions (Xanthos and Walker, 2017).

The impacts of plastic debris on cetaceans include ingestion of plastic (e.g. direct ingestion or via trophic transfer through their prey) and entanglement (Kühn *et al.*, 2015). It has been reported that over 60% of all cetacean species worldwide are adversely affected by marine plastic pollution (Fossi *et al.*, 2018a; Kühn and Franeker, 2020).

Today, the main paths pursued to solve the so-called plastic crisis focus on technological solutions, the banning or taxing of certain single-use plastic items and the promotion of plastic substitutes. Those measures are certainly helping to lighten the burden of plastic debris in the environment. Yet it is argued that more profound changes (i.e. systemic change) at the behavioural, economic, and political level are needed to address the main cause of plastic pollution which is over-production and over-consumption, in particular of single-use plastic products (World Economic Forum, 2016). It has also been suggested that non-recyclable or non-reusable plastics which are made of potentially toxic chemicals should be classified as hazardous. This could lead to a dramatic reduction of plastic waste. These hazardous items should be replaced by ones made from reusable and non-toxic materials (Rochman *et al*., 2013).

This chapter briefly illustrates the challenges of production, waste management, input sources and the fate of plastic in the oceans. It further seeks to highlight the impact of plastic debris on cetaceans. This is a high-level overview rather than a comprehensive one, due to space limitations.

A definition of plastic

"Plastics are a class of synthetic organic polymers composed of long, chain-like molecules with a high average molecular weight. Many common classes of plastics are composed of hydrocarbons that are typically, but not always, derived from fossil fuel feedstocks (Am. Chem. Counc., 2015). During the conversion from resin to product, a wide variety of additives—including fillers, plasticizers, flame retardants, UV and thermal stabilizers, and antimicrobial and coloring agents—may be added to the resin to enhance the plastic's performance and appearance." (Law, 2017)

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1 IMO (International Maritime Organization), International Convention for the Prevention of Pollution from Ships (MARPOL), Annex V. Available at: https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx

2 https://web.unep.org/unepmap/regional-plan-marine-litter-management-mediterranean-prevent-and-eliminate-pollution-enters-force

3 https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32008L0056&from=EN

Plastic production and waste management

Since the mid-twentieth century when commercial plastic production took off with around 2 million tonnes produced per year, plastic manufacturing has increased almost exponentially to 360 million tonnes in 2018 (Geyer *et al.*, 2017; PlasticsEurope, 2019a). Worldwide plastic production is expected to further increase dramatically during the next three decades (see Figure 1; World Economic Forum, 2016). In 2018, 17% of worldwide plastic production was in Europe (PlasticsEurope, 2019a).

In Europe, three main production categories of plastics can be observed: around 40% are single-use packaging designed for short-term usage, 20% are consumer applications with an intermediate lifespan (e.g. vehicles, electronic devices, household engineering), and 20% are long-term infrastructure (e.g. buildings, constructions) (PlasticsEurope, 2019a). The remaining 20% include other applications such as medical and mechanical engineering and agriculture.

Most types of plastics are produced from crude oil or gas (i.e. non-renewable natural resources) that undergo chemical processing. Today around 6-8% of the world's oil and gas production is used for the production of plastic with half of it being used as a basic raw material and half as an energy source for manufacturing the plastic (Hopewell *et al.*, 2009; World Economic Forum, 2016). It is estimated that by 2050 worldwide plastic production will account for 20% of total oil consumption and 15% of the global annual carbon budget (World Economic Forum, 2016).

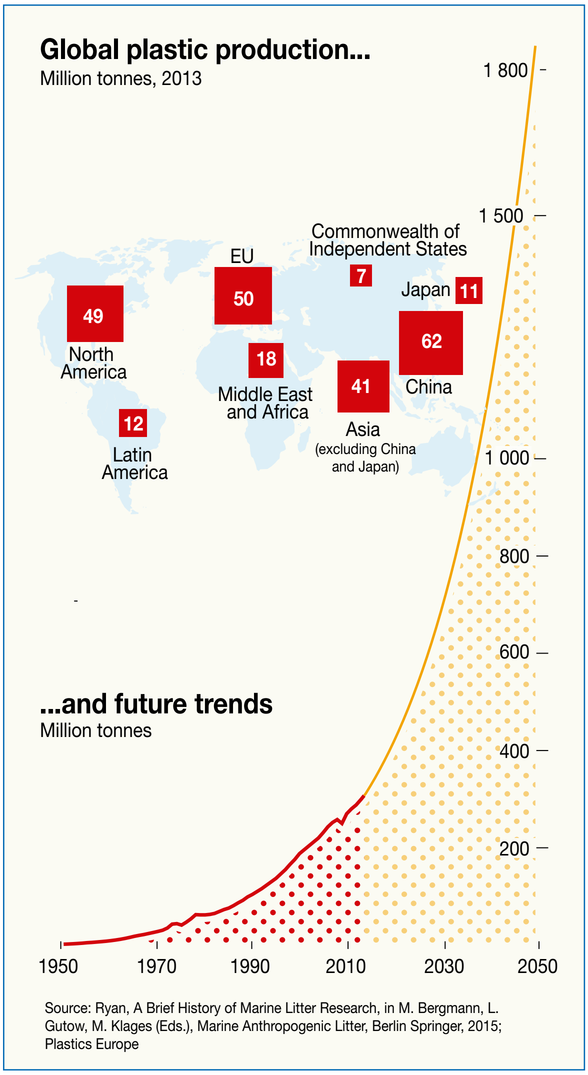


Figure 1: Global plastic production in the past and future trends (in million tonnes). *© Maphoto/Riccardo Pravettoni; http://www.grida.no/resources/6923*

According to a recent study, 8,300 million tonnes of plastic was manufactured worldwide between 1950 and 2015. In the same period, 6,300 million tonnes of plastic waste was generated of which 9% was recycled, 12% incinerated, and 79% was disposed of in landfills or in the natural environment. It is predicted that without countermeasures in production and waste management the amount of plastic waste discharged into landfills and into the natural environment will more than double in the next 35 years (i.e. amounting to 12,000 million tonnes) (Geyer *et al.*, 2017).

Sixty-one per cent of the plastic waste stream in Europe is comprised of packaging (PlasticsEurope, 2019b). In 2018, 24.9% of the total amount of collected plastic waste (= 29.1 million tonnes) ended up in landfills, 32.5% was recycled, and 42.6% was incinerated for energy recovery (PlasticsEurope, 2019a). It is noteworthy that, despite progress in recycling and energy recovery, plastic waste treatment differs quite remarkably between countries in Europe and landfills are still a first or second option in many European countries (PlasticsEurope, 2019a).

A major proportion of the plastic waste collected for recycling in Europe is exported to non-European countries for further processing. China had long been the most important recipient of non-domestic plastic waste worldwide until the country restricted plastic waste imports in 2017 (BIR, 2018). For instance, in 2012 EU Member States exported almost 50% of the plastic waste collected for recycling to China (Velis, 2014). Since 2017, some EU plastic waste export streams have shifted mainly to South East Asian countries (e.g. Malaysia, Taiwan, Indonesia, Vietnam). As these countries often have lower environmental standards when compared with European countries, concerns over the sustainability of local resource recovery practices arise (Velis, 2014).

Plastic inputs and the fate of plastic in the oceans

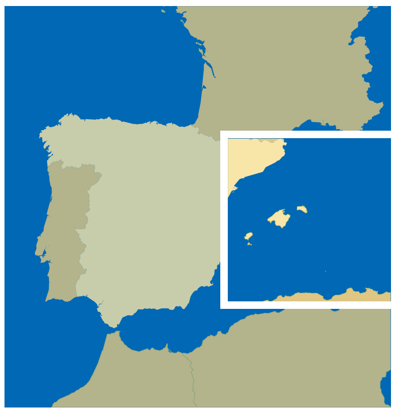
Most types of plastics do not biodegrade and therefore endure in the environment for decades, even centuries (Hopewell *et al.*, 2009). Plastic waste floats in the oceans, is carried by ocean currents, accumulates in ocean gyres, sinks to the ocean floor and can be found on beaches where it is washed up from the ocean or disposed of directly. There is still a considerably limited amount of data available on plastic waste flows to the ocean and on the respective amount of plastic contained in the various parts of the ocean. However, estimates are that currently over 150 million tonnes of plastics circulate in the oceans containing approximately 23 million tonnes of chemical additives of which some are persistent and toxic (World Economic Forum, 2016).

Eighty per cent of marine plastic debris comes from land-based sources finding its way, via untreated wastewater, the wind and rivers as well as directly from the beach, to the oceans (Ramirez-Llodra *et al.*, 2011). The remaining 20% of marine plastic debris originates from sea-based activities such as fisheries (vessels and aquacultures), shipping (merchant vessels, ferries, cruise ships, pleasure crafts, naval vessels), and offshore oil and gas platforms (UNEP, 2005). Abandoned, lost or otherwise discarded fishing gear (ALDFG), also known as ghost gear, is assumed to account for about 10% of marine debris in the oceans (Macfadyen *et al.*, 2009). It is estimated that marine plastic waste contamination from sea-based activities amounts to 1.75 million tonnes annually worldwide (Eunomia, 2016b).

Despite 80% and 20% being a common approximation of the contribution of land- and sea-based sources of marine plastic litter, the proportions of these sources may vary in marine regions and in distance from coastal development (Pham *et al.*, 2014; Eunomia, 2016b; Macfadyen *et al.*, 2009). For instance, in the German Bight ships have been identified as a main source of litter washed up on the shore (Vauk and Schrey, 1987). Furthermore, research in European waters has shown that fishing is the main source of plastic litter on the seafloor far away from coastlines, whereas close to shore, land-based sources of plastic litter are predominant (Pham *et al.*, 2014).

An estimated amount of 4.8-12.7 million tonnes of mismanaged plastic debris ends up in the oceans annually from coastal populations living within 50 km from the coastline (Jambeck *et al.*, 2015). Recent findings indicate that in addition to this, 0.79-1.52 million tonnes per year enter the oceans from inland sources via rivers (Lebreton *et al.*, 2017). For EU countries the estimated plastic waste emissions from the coast range from 54,000 to 145,000 tonnes per year, whereby the proportion from rivers is estimated to be between 1-14% of this (Eunomia, 2016b). It is noteworthy that the effluents of wastewater treatment plants into river systems may be a considerable source of microplastics even if the capture rates are high (Browne *et al.*, 2011; Leslie *et al.*, 2017).

A part of the plastic debris in the oceans floats. Recent research concludes that 233,500 tonnes of macro- and mesoplastic and 35,500 tonnes of microplastic debris float in the world's oceans (Eriksen *et al.*, 2014). Whilst macroplastic accounts for the highest amount of floating plastics by mass, microplastic is far more abundant in terms of plastic particle counts (Eriksen *et al.*, 2014; see Figure 2). The North Atlantic and Mediterranean Sea have been shown to account for roughly 21% and 9%, respectively, of the total mass of 269,000 tonnes of plastics afloat at sea worldwide (Eriksen *et al.*, 2014). Moreover, two major accumulation zones of floating plastics have been identified in Europe: the Mediterranean Sea due to high coastal human pressure and "trapping-like" hydrodynamic characteristics (Lebreton, 2012; Cózar *et al.*, 2015) and the North Atlantic (Greenland and Barents Seas) being the impasse of the oceanic large-scale surface circulation in the North Atlantic (Cózar *et al.*, 2017).



As well as the 5 great garbage patches that are recognised in the Pacific, Atlantic and Indian Oceans, the Mediterranean Sea could be considered the site of the world's 6th great garbage patch as there are comparable average densities of marine plastic litter, for example around the Balearic Islands.

There is growing scientific evidence, that the sea floor is a major sink for marine macroplastic and microplastic debris (Chiba *et al.*, 2018; Woodall *et al.*, 2014; Barnes *et al.*, 2009; Leslie *et al.*, 2017; Cózar *et al.*, 2014). Importantly, it has been reported that over 90% of macroplastics found in the deep seas are single-use products (Chiba *et al.*, 2018). Seafloor compartments in the North-East Atlantic Ocean, the southern Celtic Sea, and in the Mediterranean Sea as well as the estuarine sediments of the North Sea are highly contaminated with plastics (Galgani *et al.*, 2000; Pham *et al.*, 2014; Leslie *et al.*, 2017; Maes *et al.* 2018; Kane *et al.*, 2020). Although a major part of microplastic in the marine environment originates from the breakdown of larger plastic items (so-called secondary microplastic; see Figure 2), the emission of primary microplastic such as synthetic textile fibres, pellets, tyre abrasions, and microbeads from cosmetics is also a contributory factor (Boucher and Friot, 2017; Eunomia, 2016a). It has been assumed that 94% of plastic debris in the oceans is on the sea floor while the remaining mass is assumed to be located on beaches (5%) and floating on the sea surface (1%) (Eunomia, 2016a). However, according to current scientific knowledge the density of litter on beaches is estimated to be higher than on the sea floor (Pham *et al.*, 2014). A recent study has shown that Arctic sea ice is also an important, though temporal, sink of microplastics (Peeken *et al.*, 2018).

Megaplastic **> 100 mm**
Examples: Abandoned, lost or otherwise discarded fishing gear (ALDFG)

Macroplastic **> 25 mm**
Examples: Plastic bottles, packaging

Mesoplastic **5 – 25 mm**
Examples: Fragments, bottle caps

Microplastics (MP) **0.0001 – 5mm**
Examples: *Primary MP:* Industrially manufactured resin pellets; microbeads; synthetic textile fibres; tyre dust
Secondary MP: Plastic particles originating from the gradual breakdown of larger plastic items

Nanoplastic (NP) **< 0.0001 mm**
Examples: *Primary NP:* Industrially manufactured NPs used in electronics, biomedical products, paints
Secondary NP: Plastic particles originating from the gradual breakdown of microplastic

(Adapted from: Boucher and Friot, 2017; MSFD, 2013; Koelmans *et al.*, 2015)

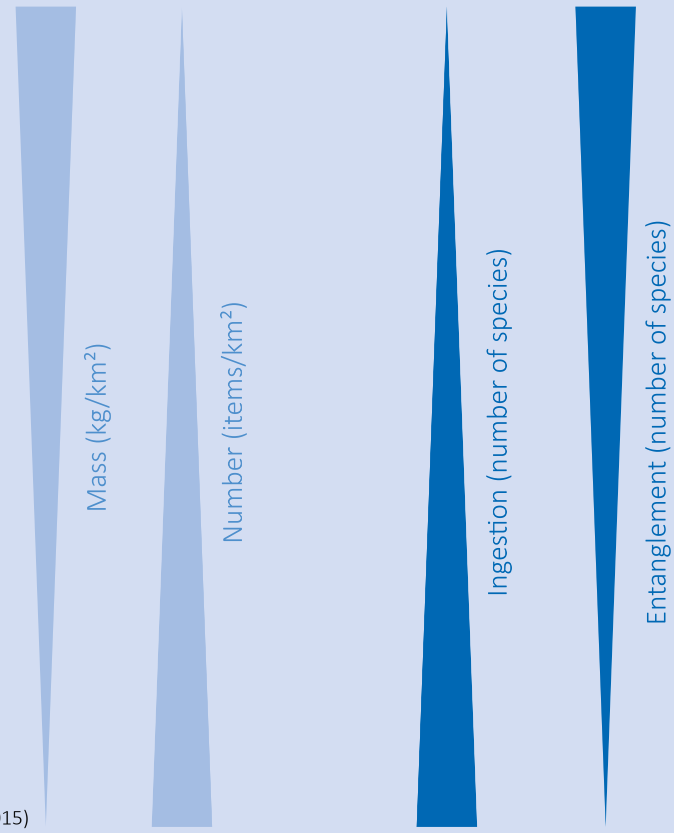


Figure 2: Selected size classes of marine plastic debris and related effects. *Depending on the size of the plastics, it is more abundant in the oceans by mass or by numbers. Likewise, size matters also with reference to the number of marine species being impacted by plastic ingestion or entanglement in plastic litter.*

Impact on cetaceans

Due to its persistence and ubiquitous occurrence in various sizes and forms, marine plastic impacts a wide range of marine invertebrate and vertebrate species (Deudero and Alomar, 2015; Kühn *et al.*, 2015; Kühn and Franeker, 2020). The impact of plastic on marine life is manifold and occurs throughout the food chain (Fossi *et al.*, 2018a; Law, 2017; Barboza *et al.*, 2019). Harmful encounters with marine debris have been described for over 800 species with plastic debris accounting for over 90% of ingestion and entanglement incidences (Fossi *et al.*, 2018b; Gall and Thompson, 2015; Schepis, 2016).

In European waters several studies document the adverse effects of plastic debris on cetaceans through entanglement and ingestion (see for instance Deudero and Alomar, 2015; Lusher *et al.*, 2015; Unger *et al.*, 2017a; Unger *et al.*, 2017b). For the Mediterranean Sea it has been shown that a major part of studied cetacean species have been impacted by marine plastic debris (Deudero and Alomar, 2015).

Macroplastic debris can act as a trap, leading to injuries as well as impeding animals' mobility and thus their ability to perform vital activities and, ultimately, causing death. Entanglements, mostly due to ALDFG, have been documented for 31% of all cetacean species worldwide (Fossi *et al.*, 2018a). Ingestion of marine debris, notably and most often plastic, has been reported for around 60% of all cetacean species (Kühn *et al.*, 2015; Kühn and Franeker, 2020; Baulch and Perry, 2014). Floating macroplastic can be mistaken as food and certain cetacean species are more likely to ingest plastic such as deep-diving toothed whales like the sperm whale (*Physeter macrocephalus*) and Cuvier's beaked whale (*Ziphius cavirostris*) due to their feeding habits (IWC, 2013). The ingestion of non-food items by sperm whales was already documented as early as the 1960s (Walker and Coe, 1990) and recent reports about the amounts of plastic debris found in stranded sperm whales in European waters is highly concerning (Unger *et al.*, 2017b; de Stephanis *et al.*, 2013; Mazzariol *et al.*, 2011; Notarbartolo di Sciara *et al.*, 2012). Once ingested, plastic debris can block and harm the digestive tract and lead to starvation and death (Laist, 1997). Apart from having direct lethal effects, ingested plastic items may lead to injury and compromise alimentation thereby decreasing overall fitness as well as increasing susceptibility to diseases (Fossi *et al.*, 2018a). To date, the ingestion of microplastics by cetaceans has been documented in just a few cases. Ingestion may occur directly from water during foraging or indirectly by ingestion of prey already contaminated with microplastics (IWC, 2013). Moreover, it is suggested that large filter feeders such as baleen whales are prone to large intakes of microplastics and therefore also of associated toxic chemicals (i.e. chemical additives contained in plastics and PBTs[4] adsorbed onto plastic particles) which may bioaccumulate in their tissues (Avio *et al.*, 2017; Fossi *et al.*, 2014).

Existing regulatory/governance frameworks

During the last decades important governance decisions and actions have been taken at global, regional, national, and local levels to reduce the emission and impact of marine plastic debris as a major form of environmental contamination. Due to space limitation, all the various initiatives and actions cannot be listed and described here. Instead, some selected examples are listed below. For further information on this subject, refer to the publications of Barboza *et al.* (2019), OceanCare (2017), and Xanthos and Walker (2017).

An important governance action at global level is the adoption of the UN Agenda 2030 with its action plan comprising different Sustainable Development Goals (SDGs) with different SDGs targeting the reduction of marine plastic debris by the UN General Assembly in 2015 (Barboza *et al.*, 2019). Further international approaches particularly relevant for cetacean conservation, include the establishment of the Code of Conduct for Responsible Fisheries which aims, among other targets, at reducing ALDFG by the Food and Agriculture Organization (FAO) and the establishment of a global whale disentanglement network by the IWC. Different European regional sea bodies adopted action plans on marine litter such as the Helsinki Convention for the Baltic Sea in 2015, the Barcelona Convention for the Mediterranean Sea in 2014, the OSPAR Convention for the North-East Atlantic in 2014, and the Black Sea Commission (action plan under development) (Barboza *et al.*, 2019).

At EU level, marine litter has been considered as Descriptor 10 within the European Marine Strategy Framework Directive (MSFD) (European Parliament and Council of the European Union, 2008). Monitoring guidance and standardized monitoring protocols for marine plastic debris have been elaborated by intergovernmental organizations and platforms as well as by expert committees such as the Joint Research Centre of the European Commission (JRC) (MSFD Technical Subgroup on Marine Litter, 2013), the International Council for the Exploration of the Sea (ICES) (ICES/IBTS, 2012), the Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans)[5], and the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) (GESAMP, 2019).

In the EU a major step in tackling environmental plastic pollution has been taken very recently through the adoption of the European Strategy for Plastics in a Circular Economy which aims to transform today's linear plastic economy into a more sustainable (circular) one in which the importance of reuse and recycling are respected.[6]

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[4] PBT = persistent, bioaccumulative and toxic chemicals
[5] http://www.jpi-oceans.eu/baseman/main-page
[6] http://europa.eu/rapid/press-release_IP-18-5_en.htm

Conclusion

Although our knowledge about the input of plastic debris into the oceans, its marine sinks and stocks as well as of the associated effects on marine life is still limited, existing field and model data show that the situation is alarming. In order to deal with this, various advances have been made in recent years to tackle marine plastic pollution. However, there is still a major need for further measures and actions at regulatory, economic, societal, and management levels in order to effectively reduce the amount of plastic waste produced as well as entering the oceans, with the aim of reducing the risks for cetaceans and other marine life posed by plastic debris.

Recommended actions

Policy

- Clear national and regional quantitative waste reduction targets should be implemented.
- An international agreement on marine plastic pollution to address and implement cross-border solutions is needed.
- Marine debris should be recognised as a threat to cetaceans and especially the deep-diving ones where reports show increasing evidence of ingestion.
- Microplastics admixture in personal care and cleaning products should be banned.
- Global extended producer responsibilities for all plastic products (including fishing gear) should be introduced.
- Clear product design requirements (e.g. with reference to recycled content and recyclability) should be put in place.
- Single-use plastics should be banned / phased out.
- Waste exports to countries with poor environmental and waste management standards should be prevented.
- The use of toxic chemicals in plastic products should be regulated using the precautionary principle.

Management measures

- Plastic waste needs to be addressed at source and the flow of plastics into the marine environment halted.
- Plastic waste should be fully processed by the countries where it has been generated in environmentally sound waste management systems.
- Marine plastic pollution (mega-, macro-, micro- and nano-plastics) needs to be monitored on beaches, in surface waters, on the sea floor and riverine bodies based on internationally harmonized protocols.
- Countries and regions should exchange technical knowledge on waste management.

Private sector

- Plastic production needs to be transformed from a linear plastic economy into a circular plastic economy.
- Massive technological development is needed in order to prevent microplastic emissions from synthetic clothes and tyre abrasions into the environment.
- Practices should be changed to avoid the generation of waste such as single-use plastic products (including plastic bags and plastic packaging) and plastic sheeting in agriculture.

Science

- Better understanding of the impacts of plastic pollution on cetaceans is needed and international initiatives such as the IWC's work on this should be supported.
- Development of a classification scheme of plastic materials according to their hazardousness.
- Research should continue on biological, ecological, social and economic impacts of marine plastic pollution as well as the plastic flows and plastic stocks in the marine environment.
- Research dedicated to informing solutions should be encouraged.

Public

- Education programmes to improve knowledge about the consequences of marine plastic pollution and necessary behavioural changes should be introduced.
- Beach clean-up programmes with associated systematic data collection based on harmonized protocols on the collected debris by the public (i.e. dedicated citizen science programmes) should be encouraged.
- The correct disposal of plastics including not leaving litter on beaches needs to be strongly promoted.
- The use of reusable shopping bags and containers over the use of single-use plastics should be promoted.
- Supermarkets and other companies should be called on to avoid unnecessary plastic packaging.

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