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# Plastics and microplastics in the oceans: From emerging pollutants to emerged threat

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ABSTRACT

Plastic production has increased dramatically worldwide over the last 60 years and it is nowadays recognized as a serious threat to the marine environment. Plastic pollution is ubiquitous, but quantitative estimates on the global abundance and weight of floating plastics are still limited, particularly for the Southern Hemisphere and the more remote regions. Some large-scale convergence zones of plastic debris have been identified, but there is the urgency to standardize common methodologies to measure and quantify plastics in seawater and sediments. Investigations on temporal trends, geographical distribution and global cycle of plastics have management implications when defining the origin, possible drifting tracks and ecological consequences of such pollution. An elevated number of marine species is known to be affected by plastic contamination, and a more integrated ecological risk assessment of these materials has become a research priority. Beside entanglement and ingestion of macro debris by large vertebrates, microplastics are accumulated by planktonic and invertebrate organisms, being transferred along food chains. Negative consequences include loss of nutritional value of diet, physical damages, exposure to pathogens and transport of alien species. In addition, plastics contain chemical additives and efficiently adsorb several environmental contaminants, thus representing a potential source of exposure to such compounds after ingestion. Complex ecotoxicological effects are increasingly reported, but the fate and impact of microplastics in the marine environment are still far to be fully clarified.



## 1. Introduction

The benefits of plastics, including versatility, resistance and durability to degradation, are well known and led to the actual definition of "age of Plastics", where almost everything contains this material. Plastic production increased dramatically worldwide over the last 60 years, passing from 0.5 million tons/yr$^{-1}$ in 1960 to almost 300 million tons in 2013. Europe ranks second at global level with 20% of the total production, corresponding to 57 million tons of plastics produced in 2012; European plastic industry gives direct employment to over 1.45 million people, generating about 26.3 billion euro for public finance and welfare (Plastic Europe, 2014/2015).

Plastic materials also pose a serious threat to the marine environment when not properly disposed or recycled. Approximately 60–80% of the word's litter is in form of plastic (Derraik, 2002), and almost 10% of the annual production ends up into the oceans, where degradation of plastic objects can take several hundred years. The main inputs of plastics into the sea derive from beaches and land-based sources like rivers, storm water runoff, wastewater discharges, or transport of land litter by wind (Ryan et al., 2009). Maritime activities contribute with materials lost by professional and recreational fishing, and debris dumped by commercial, cruise or private ships (Cooper and Corcoran, 2010). Plastic accumulation in the marine environment produces several negative repercussions: from the aesthetic impact of litter and economic costs for beach cleaning, to adverse biological and ecological effects which, according to last conservative estimates from UNEP, would cause an overall economic damage to marine ecosystems of $13 billion each year (Year Book and Valuing Plastic, Nairobi, 2014).

Considering the new evidence on the multiple risks that plastics pose to the environment, marine protection projects such as the Marine Debris Program of the US National Oceanographic and Atmospheric Administration (NOAA), included plastics litter as an emerging form of contamination. The growth of scientific interest

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has been accompanied by important normative and political decisions. The European Marine Strategy Framework Directive (MSFD, 2008/56/EC) included marine litter among Descriptors used by member States to achieve good ecological status, and international Experts Committees (like ICES or GESAMP) worked to define standardized protocols for monitoring plastic pollution in environmental matrices. In 2013, Contracting Parties of the Barcelona Convention agreed on Marine Litter Regional Action Plan to prevent, reduce and remove marine litter from the Mediterranean through developing technical capacity, reducing knowledge gaps and providing financial resources. JPI Oceans launched in 2015 a €7.5 million call for proposals to increase the knowledge on microplastics in the marine environment. In the same year, the G7 Science Ministers meeting acknowledged the global risks posed by plastics to marine and coastal life, ecosystems and potentially human health, committing a priority Action Plan to Combat Marine Litter through innovation, education, research and outreach programs.

### *1.1. Plastics materials and microplastics formation*

There are many typologies of plastic polymers and additives, which can be combined in objects with specific properties and characteristics. The most common polymers are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinylchloride (PVC), polyamide (PA), polyethylene terephthalate (PET), polyvinyl alcohol (PVA). Once released in the ocean, their environmental fate primarily depends on the polymer density (Table 1), which influences buoyancy, position in the water column and the consequent possibility to interact with biota (Wright et al., 2013b). Polymers denser than seawater (like PVC) will sink, while those with lower density (e.g. PE and PP) will tend to float in water column. Processes like biofouling and the colonization of organisms on the plastic surface increase the weight of particles, thus accelerating their sinking on bottom sediments (Ye and Andrady, 1991; Lobelle and Cunliffe, 2011); also degradation, fragmentation and the leaching of additives can change the density of objects and their distribution along the water column.

Degradation is a sequence of chemical changes that drastically reduce the average molecular weight and mechanical integrity of the polymer, mostly modulated by reactions like photo- and thermal-oxidation, hydrolysis and biodegradation mediated by microbial activity (Singh and Sharma, 2008). Degradation rate can vary according to polymer typology, presence of chemical additives, oxygen availability to the system, environmental temperature. Compared to beaches, where temperature may raise up to 40 °C in summer, plastic weathering is markedly slower in colder seawater and marine sediments (Andrady, 2011). Coupled with physical abrasion, such as wave action and sand grinding, degradation leads to embrittlement and fragmentation. Extensively degraded plastics become brittle enough to fall apart into powdery fragments and microsized plastics, typically not visible to the naked eye, called microplastics (Barnes et al., 2009).

**Table 1**
Density range of most common polymers of environmental relevance.

| Matrix | Density (g/cm$^3$) |
|---|---|
| Distilled water | 1 |
| Sea water | 1.025 |
| Polyethylene (PE) | 0.93–0.98 |
| Polypropylene (PP) | 0.89–0.91 |
| Polystyrene (PS) | 1.04–1.11 |
| Polyvinylchloride (PVC) | 1.20–1.45 |
| Polyamide (PA) | 1.13–1.5 |
| Polyethylene terephthalate (PET) | 1.38–1.39 |
| Polyvinyl Alcohol (PVA) | 1.19–1.35 |

Microplastics are generally referred to particles with a grain size lower than 5 mm, although a recent definition suggests to consider fragments smaller than 1 mm (Browne et al., 2015). Their presence has been reported worldwide, from polar regions to the equator, from intertidal zone to abyssal sediments (Zarfl and Matthies, 2010; Lusher et al., 2015; Van Cauwenberghe et al., 2015a). Microparticles can be defined as primary or secondary, depending on their origin source (Barnes et al., 2009). Majority of microplastics in the oceans are secondary products derived from degradation and fragmentation of mesoplastics or larger fragments (Gregory and Andrady, 2003); primary microplastics, introduced directly into the oceans via runoff, are manufactured as micron-sized particles typically used as exfoliants for cosmetic formulations, in industrial abrasives and 'sandblasting' media, in textile applications and synthetic clothes (Gregory, 1996; Maynard, 2006; Fendall and Sewell, 2009).

Firstly reported in 2004 in beach sediments of the United Kingdom (Thompson et al., 2004), since then the scientific interest toward this issue has exponentially increased. Searching for "microplastic" in Scopus indexed journals, 9 documents were published until 2010 in Environmental Sciences, while the number increased to 129 in 2011–2015. Microplastics have thus passed from being considered emerging pollutants to be recognized as an emerged threat, with the urgent need to better assess their distribution in the oceans, as well as the ecotoxicological and ecological risks that these particles pose to the marine ecosystem.

## 2. Distribution, behaviour and occurrence of microplastics in marine environment

Quantitative estimates of the global abundance and weight of oceanic plastics are still limited and often controversial, particularly for the Southern Hemisphere and more remote regions (Lusher, 2015). Several global surveys were carried out in the last 5 years to assess the load of floating macro and microplastics (Cózar et al., 2014; Eriksen et al., 2014; Reisser et al., 2015), and a more limited number of studies focused on their presence in sediments and biota (Lusher et al., 2013; Avio et al., 2015b; Romeo et al., 2015; Van Cauwenberghe et al., 2015a). Data from different studies are often difficult to compare due to the lack of standardized sampling methodologies, normalization units and expression of data, as well as definition, size and characterization of described microplastics (Ryan et al., 2009).

Despite these technical aspects, distribution of plastics has been documented in several seas, with highly variable concentrations, normalized to either surface or volume units (Table 2). High concentrations of plastics debris were firstly observed in the North Pacific central gyre (Moore et al., 2001) and the term "ocean garbage patches" has then been introduced (Kaiser, 2010; Zhang et al., 2010). A minimum of 21.290 tons of floating plastic debris was estimated in the accumulation zone of the North Pacific subtropical gyre (Law et al., 2010). At now, a total of 5 ocean gyres have been identified (North Atlantic, South Atlantic, South Indian, North Pacific and South Pacific), and another garbage patch was predicted to occur in the Barents Sea (van Sebille et al., 2012).

Almost 270.000 tons of plastic would be currently floating in the oceans according to results of 24 expeditions (2007–2013) across all five sub-tropical gyres, costal Australia, Bay of Bengal and the Mediterranean Sea during which surface net tows and visual survey transects of large plastic debris were conducted (Eriksen et al., 2014). Based on the total number of the plastic particles and their weight, researchers calibrated these data on an oceanographic model of floating debris dispersal corrected for wind-driven vertical mixing, estimating a minimum of 5.25 trillion particles weighting 268.940 tons.