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Ten inconvenient questions about plastics in the sea

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ABSTRACT

This paper aims to investigate some of the hottest issues that concern the increasing presence of plastics in the sea. In an attempt to identify the main knowledge gaps and to suggest future research, we discuss priority topics on marine plastic pollution through ten thought-provoking questions on the current knowledge of multiple consequences of plastics on the marine ecosystem. Our investigation found that the majority of knowledge gaps include not only intrinsic aspects of plastics (*e.g.* quantification, typology, fate), but also biological, ecological and legislative implications (*e.g.* ingestion rate by wildlife, biomagnification across food webs, spread of alien species, consequences for human nutrition, mitigation measures). The current scenario shows that science is still far from assessing the real magnitude of the impact that plastics have on the sea. In particular, the transfer of plastics across marine trophic levels emerged as one of the most critical knowledge gaps. Current regulations seem not sufficient to tackle the massive release of plastics into the sea. Within this complex picture, a positive note is the ever-increasing public awareness. The release of plastics into the sea is certainly a serious environmental issue that can be effectively addressed only through the combined efforts of the three main stakeholders: ordinary citizens through more eco-friendly behaviours, scientists by filling knowledge gaps, and policymakers by passing conservation laws relying on prevention and scientific evidence.

Introduction

Plastic is a material that has existed for over one century, and provides a wide range of societal benefits in the fields of industry, construction, medicine and food preservation (Geyer et al., 2017). Plastic became soon a basic component for manufacturing numerous everyday products, and since the 1950s, its production has increased exponentially (PlasticsEurope, 2017). This has led to the definition of "Age of Plastics", where almost all human products contain this material (Amaral-Zettler et al., 2015). At the same time, however, mass production of plastics resulted in growing environmental concerns due to inadequate waste disposal, ubiquitous distribution and slow degradation rates, even of centuries (Andrady, 2015; Jambeck et al., 2015). Plastic products offer short-term benefits but their longer-term impact is rarely assessed (Rochman et al., 2013). In particular, the ever-increasing quantity of different plastic debris entering the seas has made plastics worldwide-recognized pollutants of economic, social and political concern, since they pose a threat to marine wildlife and ecosystems, industry, and food security (Ivar do Sul and Costa, 2014; G7, 2015). The first important studies on the occurrence of plastics in marine environments go back to the 1970s (*e.g.* Carpenter et al., 1972). However, despite the long-standing scientific interest, there are still significant gaps of knowledge on the impact of plastics released into the sea, and mitigating the effects of plastic debris is a challenging priority of current conservation policies (Clark et al., 2016). Given the ever-increasing quantity of plastics in the marine environment, identifying key areas for further understanding the multiple consequences of plastic pollution is of the utmost urgency. This paper reflects the growing concern for the uncontrolled release of plastics into the sea, the numerous knowledge gaps of their ecological impact, and the urgent need to implement mitigation measures. Compared to previous studies (Vegter et al., 2014; Seltenrich, 2015; Rochman et al., 2016; Borrelle et al., 2017), we developed a list of ten research questions encompassing the main aspects of plastic release into the sea such as total amount, origin and fate, ecological impact, biomagnification, effects on marine life, and legislative issues. To select the scientific topics, we searched the Scopus Literature Database until January 2018 for articles regarding marine plastic pollution by using different combinations of the keywords "marine pollution", "plastic pollution", "plastic debris", "plastic litter", and "marine wildlife". We first compiled a preliminary list of questions that were then reduced to ten fundamental research questions by removing redundant topics. These ten questions were reported in no order of priority, and per each question, after discussing the general state of information, we pointed out current knowledge

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gaps and suggested future lines of research. Answering these ten "inconvenient" questions will also provide solid scientific evidence to guide actions of management and mitigation of marine plastic pollution.

Question 1: are there realistic estimates of the quantity of plastics released into the sea?

Plastic production increased rapidly worldwide over the last 60 years: 0.50 million tons/year in 1960 (Beall, 2009), 30 million tons/year in 1988 (O'Hara et al., 1988), 265 million tons/year in 2010 (PEMRG, 2011), 300 million tons/year in 2015 (PlasticsEurope, 2015), up to 335 million tons/year in 2016 (PlasticsEurope, 2017). Only 4 to 6% of all the oil and gas used in Europe is employed in the production of plastic materials, and in the last ten years, over 2.6 billion tons of plastics were produced globally (PlasticsEurope, 2017). Geyer et al. (2017) estimated that 8300 million metric tons (Mt) as of virgin plastics have been produced to date, and that since 2015, approximately 6300 Mt of plastic waste had been generated, around 9% of which had been recycled, 12% was incinerated, and 79% was accumulated in landfills or the natural environment. If current production and waste management trends continue, about 12,000 Mt of plastic waste will accumulate in landfills or in the natural environment by 2050 (Geyer et al., 2017). In particular, Europe ranked second at global level with 20% of the total production, amounting to 60 million tons of plastics produced in 2016, and giving job to over 1.50 million people, supporting about 60,000 companies, with a turnover close to 350 billion euros in 2016, which contributed to 30 billion euros to public finances and welfare in 2016 (PlasticsEurope, 2017). Around 60–80 % of the world litter is of plastic origin (Derraik, 2002), and although plastics are internationally recognized pollutants subjected to legislation aimed to mitigate the amount of plastic debris released into the sea (Lozano and Mouat, 2009), Thompson (2006) assessed that up to 10% of plastics globally produced enter the marine environment annually, where they can accumulate and persist for hundreds of years. However, according to Jambeck et al. (2015), between 4.8 and 12.7 million tons of plastics are believed to have ended up into the sea in 2010 from terrestrial sources, resulting in 1.8–4.8% of the total plastics produced globally, a figure significantly lower than the 10% reported by Thompson (2006).

Another aspect is assessing the aliquot of plastics in the sea that float on the marine surface. Almost 270,000 tons of plastics are supposed to float currently in the oceans according to the data collected in 24 expeditions (2007–2013) across all five sub-tropical gyres, Australian coasts, Bay of Bengal and the Mediterranean sea (Eriksen et al., 2014). Other estimates relying on global surveys (Cózar et al. 2014; Eriksen et al. 2014) and different models of surface ocean transport (Lebreton et al. 2012; Maximenko et al. 2012), found a value of the total buoyant plastics (< 200 mm in size) ranging between 93,300 and 236,000 tons (van Sebille et al., 2015). However, even considering both larger plastics (> 200 mm in size), which are likely to be more than 70% of the total mass of plastics at the marine surface (Eriksen et al., 2014), and thick plastic debris that rapidly sink to the seafloor, it is still difficult to reconcile the aliquot of floating plastics with estimates of total plastic inputs into the sea (Clark et al., 2016), suggesting that plastics are removed from the marine surface through unknown processes.

Several global surveys were carried out in the last few years to assess the amount of floating macro- and micro-plastics (Cózar et al., 2014; Reisser et al., 2015), and some studies investigated also their presence in sediments and biota (Lusher et al., 2013; Van Cauwenberghe et al., 2015). However, quantitative estimates of the global abundance of marine plastics are still limited and disputed, especially for remote regions (Lusher et al., 2015). In the light of the current studies and available data, we are still unable to provide precise estimates of the global quantity of plastics into the sea. Indeed, although we know the annual world production of plastics and the information from numerous global surveys is available, there are still significant discrepancies between the estimated quantity of plastics released into the sea and the quantity of marine plastics surveyed and forecasted. Realistic estimates of marine plastics are also hampered by lack of uniformity in the approach to quantification (Ryan et al., 2009). This includes lack of standardized sampling methodologies as well as lack of standardized definition, size and characterization of marine plastics (Ryan, 2013). Plastic debris first enters coastal waters and then, through numerous biological and hydrogeological processes, reaches open sea (Cole et al., 2011). However, quantifying plastic debris in the open sea is challenging due to economics (*e.g.* ship costs for dedicated surveys) and the huge spatial areas that need to be surveyed (Morishige et al. 2007). Ships of opportunity (*e.g.* commercial vessels) used for monitoring plastics debris in the open sea do not seem sufficient for exhaustive surveys (Reisser et al., 2013). In the future, surveys may also rely on satellite imagery of the sea surface to estimate the abundance of plastic debris (Vegter et al., 2014). Overall, field techniques currently used for oceanographic studies in the open sea need further refinement and development to quantify the load of plastic debris (Hidalgo-Ruz et al., 2012; Eriksson et al., 2013). Quantifying the inputs of plastic debris into the marine environment is also difficult for the vastness of the oceans compared to the size of plastics. Moreover, spatial and temporal variability of plastics due to oceanic currents and seasonal patterns further complicate their quantification (Doyle et al., 2011). Regular and widespread surveying of coastal areas seems thus one of the best feasible approaches to provide realistic estimates of marine plastics, provided that their assessment is also accompanied by the refinement of sampling methodologies and the standardization of size definitions.

Question 2: do we know all the sources of plastics that end into the sea?

Marine plastic debris originates from the indiscriminate disposal of waste materials that are directly or indirectly transferred to the sea (Law, 2017). Sources of plastic pollution are numerous and diverse, and generally divided into two large categories: ocean- and land-based plastics, with land-based debris considered as the major one (Sheavly and Register, 2007). Land-based plastic debris is generally of urban and industrial origin, and can reach the sea through several ways, like rivers, storm water runoff, wastewater discharges or litter dumping by beach users (Corcoran et al., 2009). For example, Lebreton et al. (2017) estimated that between 1.15 and 2.41 million tonnes of plastic waste currently enter the ocean every year from rivers, with over 74% of emissions occurring between May and October. In particular, they found that the top 20 polluting rivers, mostly located in Asia, account for 67% of the global total. Moreover, Willis et al. (2017) showed that significant sources of plastic debris include direct deposition by beachgoers, transport from surrounding areas *via* storm water drains and coastal runoff, and onshore transport from the marine system. While wastewater treatment plants can trap macroplastics and some small plastic debris within oxidation ponds or sewage sludge, a great aliquot of microplastics can pass through such filtration systems in case of lack of advanced final-stage wastewater treatment technologies (Kalčíková et al., 2017; Talvitie et al., 2017; Li et al., 2018). Plastic debris from terrestrial sources amounts to c. 80% of plastics released into the sea (Geyer et al., 2017). Such plastics include primary microplastics originated from *e.g.* facial-cleansers, cosmetics, air-blasting, or leachates from waste dumps, but also granules and small resin pellets, known as "nibs", are another significant source of land-based plastic debris (Fendall and Sewell, 2009; Browne et al., 2011; Napper et al., 2015). In particular, resin pellets are ubiquitous items that can be detected in all marine environments worldwide, even around oceanic islands without local plastic manufacturing industries (Ivar do Sul et al., 2009). With about half the world's population living within 100 km from the coast, rivers and wastewater systems act as the main routes for land-based plastic debris to enter the sea (Browne et al., 2010). Extreme