

Microplastics in the marine environment

A threat to marine biota?

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Abstract

Microplastics in marine environments are an emerging environmental problem of international concern. This review focuses on the sources, quantities and effects of microplastics, to assess whether or not they pose a threat to marine biota. Microplastics are ubiquitous in marine environments, and have been reported along shorelines, in surface waters, seabed sediments, watercolumn and in a wide range of biota, from the Arctic to Antarctic. Particularly high concentrations have been measured in sub-tropical ocean gyres, close to population centers and in enclosed seas, like the Mediterranean. Measurements over time have also revealed that the smaller fragments are increasing. These have more surface area per unit mass, and are therefore likely to exhibit more intrinsic toxicity. Their small size also makes them bioavailable to a much wider variety of organisms, than larger plastic debris. Microplastics can therefore act as a carrier of chemicals (either adsorbed from surrounding seawater, or incorporated in the plastic) to marine biota. Few field studies have attempted to investigate the effects of microplastic exposure, however, indications of harmful effects have been revealed in several laboratory studies. These include reduction in the function and health of zooplankton, hindered algal photosynthesis and accumulation in mussels, causing a strong inflammatory response. The potential impact on the base of the food chain represents a primary concern, as it could affect the productivity of the entire ecosystem.

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Introduction

Microplastics in marine environments are an emerging environmental problem of international concern. It is an interdisciplinary issue, requiring the attention of both the scientific- and the political community.

Within the past few decades the annual production of plastic has increased drastically, from 1.7 million tons in 1950 (PlasticsEurope, 2013) reaching 311 million tons in 2014 (PlasticsEurope, 2015). To get a better picture of this overwhelming amount, 311 million tons of plastic divided evenly on the entire world population would be approximately 43 kg per person per year. If you divide this further with the weight of one plastic carrier bag this would mean approximately 2400 plastic carrier bags for every person on earth each year. This development has led to an accumulation of plastic debris in terrestrial environments, along shorelines, in the open ocean and even in the deep sea (Barnes et al., 2009). The accumulation and impact of plastic litter appears to be most serious in marine environments (Ryan et al., 2009) and therefore this will be the focus of this study .

For a long time the accumulation of plastic debris in marine environments was only perceived as an aesthetic problem and was therefore also greatly ignored (Derraik, 2002). However, with accumulating data on ecological consequences of such debris in recent decades, the seriousness of the problem has been recognized and is now a high-priority research area in Marine Biology (Stefatos et al., 1999, Andrady, 2011).

Since light plastic debris is easily transported, it has become a global problem, contaminating even the most remote islands (Barnes, 2002, Ryan et al., 2009). The ubiquity and abundance of the problem, the ever increasing uses of plastic and its persistence in the environment are some of the aspects that make this problem especially challenging.

According to Laist (1997) plastic pollution of the marine environment affects at least 267 species worldwide, including 86% of all sea turtle species, 44 % of all seabird species, and 43 % of all marine mammal species. The threats of macroplastics to marine life are primarily mechanical, through ingestion of or entanglement in drifting plastic debris (Laist, 1987). However, less is understood about the threats of microplastics at present time and many aspects of the problem need further research.

The purpose of this study is to discuss the potential environmental impact of microplastics once they have ended up in marine environments. The goal is to understand more about its sources, quantities and distribution, so as to be able to assess whether or not they pose a threat to marine biota at present time or in the future. The questions that will be discussed and hopefully answered to some degree are as follows:

- What are the sources of microplastics?
- What do we know about the quantities and distribution of microplastics in marine environments?
- Are microplastics in marine environments a threat to marine biota?

Method

To answer the environmental problems linked to microplastic and the more specific questions listed above, a literature review was performed. Relevant studies were gathered throughout April and the beginning of May 2015 using the database Web of Science. Some further research was done in October 2015. The literature review was set up in three steps, which is align with the general approach advised for literature reviews. Of course three steps is a simplified description of the process but covers the areas of scoping, searching and categorizing (Hart, 1998).

Scoping: As a first step, to get an overview of the topic, the first search that was made was the phrase "Microplastics in marine environments". This search phrase had its point of departure in the pre-understanding of the topic elaborated in the introduction of this thesis and the aim of the study.

Upon reading the abstracts of the studies and reviews with seemingly relevant titles a selection was made. "Seemingly" relevant was judged in relation to the aim of the study, hence articles dealing with the issues dealt with in the research questions were selected. After reading these articles thoroughly, I noticed that several authors and studies were being referred to repeatedly, and so I searched for these by title or author. In the same way, these were also included or excluded based on the relevance of the abstract. In this step I also identified several reviews over the area which were used as another and rich source for relevant articles. These articles were read and their literature lists were searched through, which is a common approach in literature reviews (Hart, 1998).

Searching: As a second step and with some knowledge about the topic, I realized that "microplastic", "marine environments", and "adverse effects" would be key words to use in further searches. Different combinations of these were also applied using the AND function. These searches also yielded some studies that were added to the selection. Studies were excluded if they were about any type of fresh water system or terrestrial environment. Some statistics found on PlasticsEurope.org and definitions established by NOAA (National Oceanic and Atmospheric Administration) were also used.

Categorizing: As a third step the articles that were found in the search were grouped in categories that were given the titles: "Definitions", "Durability", "Sources of microplastics", "Distribution and abundance of microplastics" and "Effects of microplastics on marine biota". Several of these categories also have sub sections.

The work of categorizing articles and assessing their relation to the research aim was as in most literature reviews an iterative process. Searching articles was also an iterative process as the reading of new articles gave a better understanding of the problem.

In the result section the found information is presented with the reference to the relevant article found in the review. Some articles may occur at several places in the section as a result of treating several identified categories in the same article.

Results

The results will be presented in 5 different parts, which represent topics that are discussed in the scientific literature. These have been given the titles: "Definitions", "Durability", "Sources of microplastics", "Distribution and abundance of microplastics" and "Effects of microplastics on marine biota". The first two chapters include some information about what microplastics are and why they are a problem, as this was identified as an issue during the review of the articles that is indirectly linked to the research questions, whereas the research questions will be addressed more directly in the last three chapters.

The references in the chapters below are from the studies selected during the research phase, the literature review of articles on micro-plastic in the marine environment.

Definitions

Plastics are organic polymers of high molecular mass. The five main high production volume plastics, and therefore also the most encountered, are polypropylene (PP), polyethylene (PE), polyvinylchloride (PVC), polystyrene (PS) and polyethylene terephthalate (PET) (Zarfl and Matthies, 2010). Together they make up about 90 % of the total plastic demand (Besseling et al., 2013). The plastic debris littering our oceans comes in all different shapes and sizes. Everything from discarded fishing nets, plastic bottles and carrier bags to less conspicuous and barely visible plastic particles. The latter were first reported in scientific literature in the early 1970s (Carpenter and Smith, 1972). Today the term "microplastic" has become widely used to describe these small pieces of plastic in the millimeter to sub-millimeter size range. However, it is unclear when the term was first used in relation to marine debris. In 2008 an upper size limit of 5 mm was suggested as a definition of microplastics, based on the premise that this definition would include a wide range of small particles that could easily be ingested by biota, and which might be expected to present different kinds of threat than larger plastic items (GESAMP, 2015). In some reports the terms nano-, micro-, meso-, macro- and megaplastic are used to describe different size intervals (e.g. Andrady 2011), while others use only micro- and macroplastic. For simplicity, only microplastic (< 5 mm) and macroplastic (>5 mm) will be used in this study.

Durability

The slow degrade of plastics is one of the factors that make them so problematic. The persistency of microplastics in the environment is a matter of some debate, with estimates ranging from hundreds to thousands of years (Barnes et al., 2009).

When discussing the degradation of plastic it is important to note the distinction between degradation and complete degradation (also called mineralization). Whereas mineralization refers to the destruction of the polymer chain and its complete conversion into small molecules (e.g. carbon dioxide and methane), degradation only refers to an alteration in the plastic's properties and fragmentation (GESAMP, 2015)

Commodity plastics are very durable in marine environments. It is believed that all the conventional plastic that has ever been introduced into the environment still persist, unmineralized either as whole items or as fragments (Thompson et al., 2005). According to Besseling et al. (2013) the durability of most macroplastics in marine environments is estimated to be in the range of 5 to 50 years before they degrade to microplastics, whereas microplastics are believed to persist for centuries. In a study on the degradation of polypropylene it was shown that the lifetime of the plastic increased with decreasing particle size (Paik and Kar, 2008). In other words, marine plastic has a much longer lifetime as a microplastic than a macroplastic.

However, even though a wide range of estimates for the time needed to biodegrade marine plastics have been made, they are all educated guesses at best (Moore, 2008) and since we have only been massproducing conventional plastic for around 65 years it is too early to say exactly how long these materials will persist (Barnes et al., 2009)

Sources of microplastic

The sources of microplastics are divided into two main categories; primary and secondary microplastics. Microplastics that were originally manufactured to be of that size belongs in the first category, whereas microplastics that derive from the breakdown of larger items belong in the second.

Primary microplastics

Primary microplastics are typically used as exfoliates in cosmetics (Zitko and Hanlon, 1991), industrial scrubbers used to blast clean surfaces (Gregory, 1996) and in the production of plastic, as virgin plastic pellets (typically up to 5 mm in diameter)

(GESAMP, 2015). Their use in medicine as vectors for drugs is also increasingly reported (Patel et al., 2009). In a study from 2011 it was estimated that 200 tons of microbeads were used annually in personal care products, in the USA alone, and that approximately 50 % of these would pass through sewage treatment to the ocean (Gouin et al., 2011). When used in airblasting technology microplastics will often be contaminated with heavy metals such as Cadmium, Chromium and Lead since the process involves blasting microplastic scrubbers at machinery, engines and boat hulls to remove rust and paint (Gregory, 1996). This category of microplastics often reaches the oceans directly with runoff. However, there is also evidence of virgin plastic pellets being lost during transport at sea. For example, in the summer of 2012, during Typhoon Vicente, a cargo ship lost 7 40-foot-long containers in the waters near Hong Kong, 6 of which contained polypropylene pellets. Approximately 150 tons in total spilled into the ocean according to Hong Kong environmental authorities. (TEIC, 2012)

Secondary microplastics

The majority of microplastics are however likely to be secondary microplastics (Andrady, 2011). They result from the weathering and fragmentation of larger plastic items which can happen both during the use phase (e.g. products such as textiles, paint and tires) or once the items have been released into the environment (GESAMP, 2015). The slow degradation of plastics usually happens through a combination of photodegradation, oxidation and mechanical abrasion. In water this can take even longer, mainly owing to the reduced UV exposure and lower temperatures found in aquatic habitats (Ryan et al., 2009). The exact rate at which this happens is unknown, but it happens with decreasing speed in these different locations; beach environments, surface water, water column, deep sea (GESAMP, 2015).

Fragmenting macroplastics are the source of secondary microplastics, and therefore some of the sources of macroplastics will also be mentioned here. Since mass production of plastics commenced in the 1950s, the annual global production has grown exponentially, reaching 311 million tons in 2014. In Europe, packaging is the largest application sector, accounting for almost 40% of the total production (PlasticsEurope, 2015). The cumulative production since 1950 is growing at an even faster pace, and amounted to approximately 6,5 billion tons in 2014, which is quite significant considering the persistency of plastic. Figure 1 shows the annual and cumulative global plastic production from 1950 to 2014.

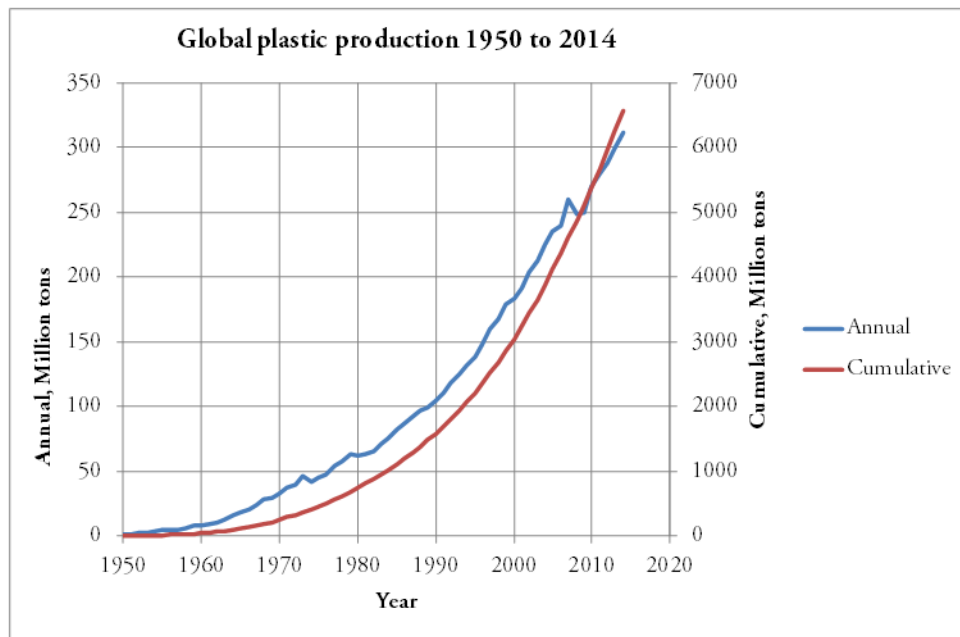


Figure 1 Annual and cumulative Global plastic production from 1950 to 2014

Left vertical axis shows the annual Global plastic production (million tons), whereas the right shows the cumulative production (million tons). This graph is plotted based on data from PlasticsEurope 2013 and PlasticsEurope 2015.

Jambeck et al. (2015) estimated that 4,8 to 12,7 million tons of plastic waste entered the ocean in 2010. This was based on data from 192 coastal countries including: (i) the mass of waste generated per capita annually; (ii) the percentage of waste that is plastic; and (iii) the percentage of plastic waste that is mismanaged. Of the mismanaged plastic waste, 15 to 40% were assumed to enter the ocean. Using a mid value of this would result in 8 million tons of plastic entering the ocean that year.

It is estimated that approximately 80 % of plastics found in marine litter has a terrestrial source (Andrady, 2011). With about half of the human population living within 50 miles of the ocean, and it being downhill and downstream from virtually everywhere, lightweight plastic trash has a high potential to enter the marine environment via rivers and wastewater systems, or by being blown off shore (Moore, 2008). Some sources of plastic that can directly enter the marine environment include coastal tourism, recreational and commercial fishing, marine vessels and marine industries (Cole et al., 2011). It has been estimated that the global commercial fishing fleet dumped over 23 000 tons of plastic packaging materials into the ocean during the 1970s, making marine vessels a significant contributor to marine litter (Pruter, 1987). Since then an international agreement to ban the disposal of plastic waste at sea (MARPOL 73/78 Annex V) has been implemented,

although the effects of this are uncertain due to a lack of enforcement (Cole et al., 2011).

Distribution and abundance of microplastics

To be able to assess the potential impacts of microplastics it is important to understand how they are distributed and in what quantity. This, however, is easier said than done considering, for example, the size of the ocean, the widespread sources and how little we know about the rates of degradation of plastic. Hence, there are no reliable estimates of how much plastic is entering the ocean at either a regional or global scale, or how much is already in there. The estimates are, however, getting better and it is reasonable to assume that the total quantities have increased what with the increase in plastic production, use and disposal since the 1950s.

Direct observations

While the northern hemisphere has the best coverage of microplastic sampling, the geographical coverage is growing each year (GESAMP, 2015) and microplastics have been reported virtually everywhere;

- Surfaces of major oceans (Moore et al., 2001, Law et al., 2010)
- Watercolumn (Lattin et al., 2004)
- Deep sea sediments (Van Cauwenberghe et al., 2013)
- Beaches worldwide (Browne et al., 2011, Ivar do Sul et al., 2009, Hidalgo-Ruz et al., 2012)
- Arctic ocean sea ice (Obbard et al., 2014)
- In a variety of biota (De Witte et al., 2014, Lusher et al., 2013)

The majority of surveys are of the sea surface and shorelines, while the data from other parts of the marine environment is scarce. The surface surveys have, however, revealed the existence of accumulation zones characterized by high concentrations of plastic debris (e.g. Moore et al. 2001; Law et al. 2010). These include sub-tropical ocean gyres, enclosed seas, such as the Mediterranean, and close to population centers (GESAMP, 2015). In the Merriam Webster dictionary a gyre is defined as "a giant circular oceanic surface current". Simply put, buoyant plastic debris is transported to these gyres and become trapped there, because of wind- and current patterns.

Modelling

In addition to direct observations, modeling has been used to predict accumulation sites. Modeling by Lebreton et al. (2012) clearly show the formation of five accumulation zones in the subtropical latitudes of the major ocean basins, with the ones in the northern hemisphere dominating both when it comes to relative size and concentration. Furthermore, they found that smaller seas surrounded by densely populated areas also have high concentrations of floating debris. These results compare well with measured concentrations of floating debris.

A more recent modeling based on surface net tows and visual survey transects from 24 expeditions (2007-2013) across all five sub-tropical gyres, coastal Australia, Bay of Bengal and the Mediterranean Sea resulted in an estimate of at least 5,25 trillion plastic particles weighing 268 940 tons floating in the world's oceans (Eriksen et al., 2014). Microplastic accounted for 92,4 % of the global particle count and 13,2 % of the weight. Hence, microplastics are far more numerous than macroplastics, which is likely to be of greater ecological significance than mass (GESAMP, 2015). 70 % of the 680 surface net tows gave estimated concentrations of 1000-100 000 pieces/km² and 16% resulted in even higher counts of up to 890 000 pieces/km² found in the Mediterranean. Figure 2 shows the locations and estimated particle concentrations from the net tows and visual survey transects, while Figure 3 shows the same from the model results.

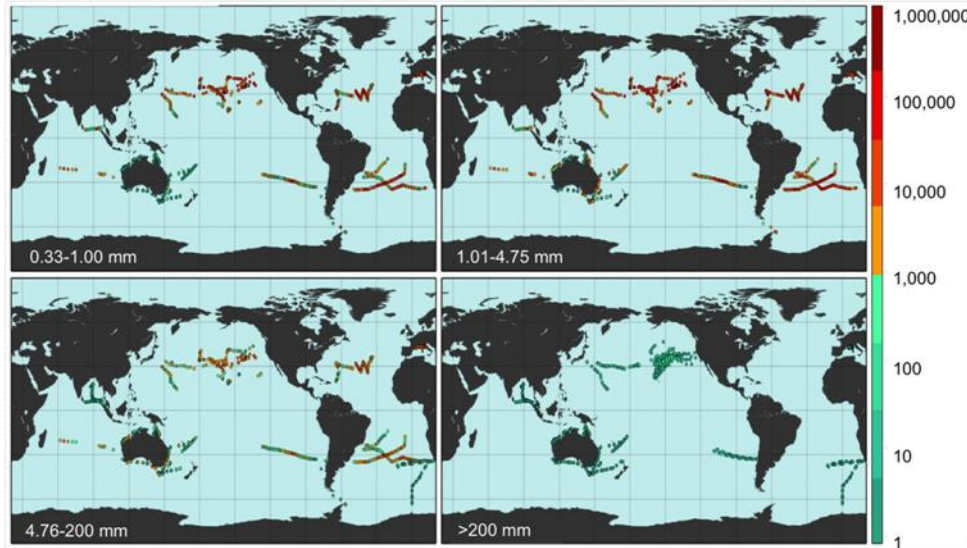


Figure 2 Field locations for measured particle concentration

Particle concentration (pieces/km², see color bar) of marine plastic debris measured at 1571 stations (680 net tows and 891 visual survey transects). The upper two maps are for microplastics divided into small (0,33-1,00 mm) and big (1,01-4,75 mm) microplastics. Source: Eriksen et al. 2014

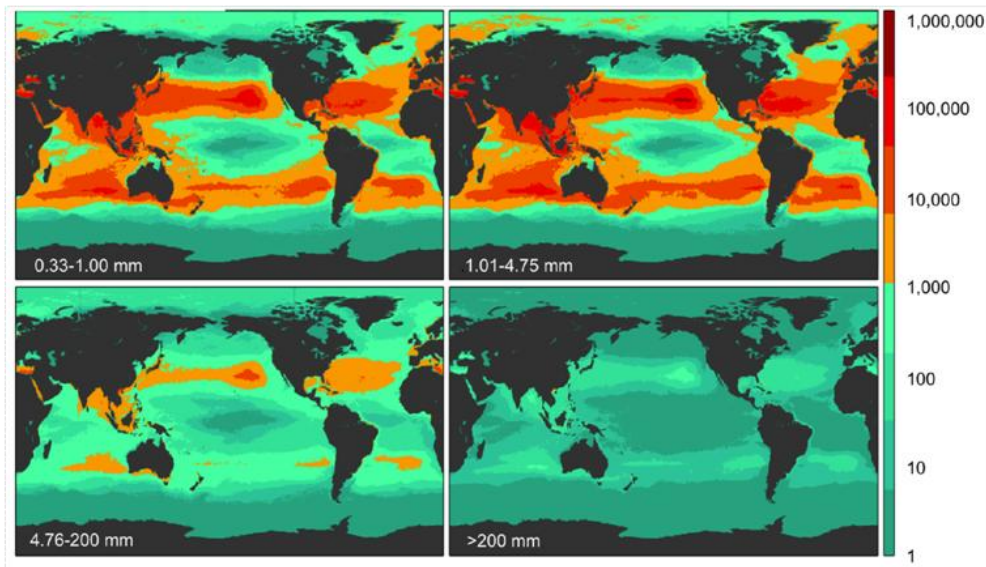


Figure 3 Model results for global particle concentration

Model prediction of global particle concentration (pieces/km²) for four size classes (0,33-1,00 mm, 1,01-4,75 mm, 4,76-200 mm and >200 mm). Upper two maps show microplastic particle concentration. Source: Eriksen et al.2014

Temporal trends

In 2004 Thompson et al. published the first assessment of microplastic abundance over time by examining plankton samples collected regularly since the 1960s between the British Isles and Iceland. Although they found that the amount of microplastics had increased significantly from the 1960s and 1970s to the 1980s and 1990s, no significant increase was observed between the later decades. Similarly, Law et al (2010) analyzed 22 years of ship-survey data collected from the western North Atlantic Ocean and the Caribbean Sea, but observed no strong temporal trend in plastic concentration.

However, studying the same archived plastic samples from the North Atlantic, Moret-Ferguson et al. (2010) found that the mean particle size had decreased with more than 50% (10.66 mm in the 1990s to 5.05 in the 2000s), and that 69% of fragments ranged from 2-6 mm in size. This could indicate that there is a trend towards an ongoing increase in the abundance of the smallest fragments of plastics.

Effects of microplastics on marine biota

The potential for microplastics to cause harm in marine organisms depends on the organisms susceptibility to interact with them (Wright et al., 2013).

Microplastics exposure routes to marine biota

Exposure routes such as ingestion, uptake through gills, translocation into tissues, cells and organelles, trophic transfer and adherence to organism surface have been reported.

The ingestion of microplastics has been demonstrated in a large variety of marine organisms including zooplankton, amphipods, lugworms, barnacles, mussels, seabirds and fish (Cole et al., 2013). Some may even be ingesting plastic particles selectively. Graham et al. (2009) found that some species of sea cucumbers ingested significantly more plastic particles than predicted given the plastic to sand grains ratio. Relatively high concentrations of microplastics have been detected in some species. For example, mussels sampled from the Belgian coast had a mean of 5,1 fibers/10 g wet weight (De Witte et al., 2014).

For species that actively feed, ingestion is probably the most important exposure route. Under the right circumstances however, inspiration across gills can also occur. Watts et al. (2014) found that the shore crab *Carcinus maenas* took up microplastics both through ingestion and inspiration across the gills. When taken up through the gills however, the plastic particles were retained in the crabs tissues for a longer time than those ingested.

Once the plastic particles have made their way into the organism, they are either eventually excreted or taken up into tissues, cells and organelles through translocation. If the latter happens, these particles could accumulate in the organism and cause harm. Marine organisms could also be exposed to microplastics indirectly through their prey. The first study to show trophic transfer of microplastics came in 2013. Mussels that were pre-exposed to fluorescent polystyrene microspheres, were fed to crabs and microspheres were then detected in the crab's haemolymph, stomach, hepatopancreas, ovary and gills (Farrell and Nelson, 2013). Trophic transfer between zooplankton and mysid shrimp has also been shown experimentally (Setälä et al., 2014). Another possible exposure route is the adherence of microplastics to organism surfaces. This has been shown experimentally with algae (Bhattacharya et al., 2010) and zooplankton (Cole et al., 2013).

Chemical effects

Plastics are considered to be biochemically inert materials due to their large molecular size which prohibits them from penetrating the cell membrane and thus no interaction with the endocrine system occurs (Teuten et al., 2009). But although the plastics in themselves are inert they often contain harmful additives, and once they reach marine environments they also tend to adsorb hydrophobic chemicals from surrounding seawater.

Additives, monomers and biproducts

During manufacture, additives are often incorporated into plastics to change their properties or extend the life of the plastic. Many of those are bioactive monomers and come in the form of UV-stabilizers, softeners, colorants, flame retardants and non-stick compounds which eventually can leach out (Moore, 2008). Overall, plastic products are estimated to contain about 50% fillers, reinforcements and additives by weight (Colton et al., 1974). Many of these have known biological consequences. For instance, the plastic constitutional monomer bisphenol A has been shown to target nuclear hormone receptor signaling pathways (Gruen and Blumberg, 2007). This bioactive monomer is a key building block in polycarbonate plastics and when exposed to the salts in seawater, leaching of said monomer is accelerated (Sajiki and Yonekubo, 2003). Another example is nonylphenol, which is added for resistance to oxidative damage (Cole et al., 2011) and has been detected in plastic resin pellets collected from Japanese coasts (Mato et al., 2001). Similarly to bisphenol A, it exerts oestrogenic effects (Sonnenschein and Soto, 1998). Flame retardants, such as polybrominated diphenyl ethers (PBDEs), are another important category of additive. These are suspected thyroid disruptors in wildlife and humans (WHO, 1994). They are however ubiquitous in coastal seawater and hydrophobic, so it is difficult to establish whether these derive from the plastic itself or if they have been sorbed from surrounding seawater (Teuten et al., 2009).

Adsorption of waterborne pollutants

Marine plastic debris is susceptible to contamination by a number of waterborne pollutants due to their low polarity surface which hydrophobic chemicals prefer to surrounding seawater (Cole et al., 2011). This is of particular concern with microplastics because of their great surface area to volume ratio (Barnes et al., 2009), allowing them to concentrate more chemicals. It has been shown experimentally that microplastics can accumulate these hydrophobic chemicals (in this case PCBs and DDE,) in concentrations up to 6 orders of magnitude higher than surrounding seawater (Mato et al., 2001).

Ingestion of microplastics has therefore been suggested as a possible exposure route for harmful chemicals (Thompson et al., 2004, Teuten et al., 2009). This effect

has been demonstrated for lugworms in laboratory experiments (Besseling et al., 2013, Browne et al., 2013) although the results were not entirely conclusive. It is still uncertain how important the role of microplastic contaminant transfer to marine organisms is. However, it has recently been demonstrated that stomach oil can act as an organic solvent, which would enhance the bioavailability of the chemicals in the plastic (Tanaka et al., 2013). In addition, a recent field study in the South Atlantic gyre revealed a positive relationship between the density of plastic debris and the bioaccumulation of PBDEs in fish (Rochman et al., 2014b), suggesting plastic-mediated transfer of persistent organic pollutants (POPs). Recent studies have shown that plastics also concentrate trace metals in seawater (Holmes et al., 2012, Rochman et al., 2014a). So far, the research on this is scarce however, and the transfer of metals from microplastics to organisms has not been studied.

Physical effects

Due to the small size of microplastics they become bioavailable to a much wider range of organisms than larger plastic debris. For the small, lower trophic level organisms, microplastics can cause similar mechanical hazards as observed for macroplastics and larger animals.

Physical effects such as entanglement, obstruction of feeding organs, reduction in feeding activity, adsorption to the organism surface and translocation into tissues, cells and body fluids have been contemplated.

Although no records of entanglement were found, it can be expected for small organisms and the larger particles. The obstruction of feeding organs, however, has been shown experimentally. In a feeding experiment, Cole et al. (2013) found that zooplankton ingested microplastics indiscriminately and microplastics were found clustered within the alimentary canal. In the same study it was demonstrated that the presence of microplastics could significantly reduce feeding activity in a dose-response relationship. Similarly, Besseling et al. (2013) observed a negative relation between plastic concentration and the activity of lugworms.

In a study of the absorption of plastic nanoparticles to algae, Bhattacharya et al. (2010) showed that this hindered algal photosynthesis. The physical blockage of light and air flow by the nanoparticles was thought to be the cause. Furthermore, the absorption of plastic nanoparticles seemed to promote oxidative stress.

Once ingested, microplastics have the potential to translocate and accumulate in organs and tissues, which may evoke an immune response. When investigating this in the mussel *Mytilus edulis*, Browne et al. (2008) found that particles translocated from the gut to the circulatory system within 3 days and persisted for over 48 days. Their data also indicated that the smaller the particles were, the higher the potential for accumulation in the tissues of an organism. Using the same test organism, von Moos et al. (2012) found that HDPE particles were both ingested and drawn into

the gills. After only 3 hours of exposure the particles had accumulated in the lysosomal system causing a strong inflammatory response. This clearly shows that microplastics have the potential to be taken up into cells and cause significant effects on the tissue and cellular level. There are, however, few studies of this kind on marine biota. In contrast, there is a magnitude of peer reviewed literature revealing that microplastics is unhealthy for humans and mammals (Brown et al., 2001, Fröhlich et al., 2009), which could give an insight into the possible risks for marine biota as well.

Discussion

Gaining knowledge about the sources of microplastic is an important step when it comes to finding solutions to the problem. Because of their size, microplastics are as good as impossible to retrieve once they have ended up in marine environments. Attacking the problem at its sources is therefore a better approach. Improving waste management will be important, focusing on the principles of the 3 Rs (Reduce, Re-use, Recycle).

However, we have a long way to go, particularly when it comes to the first R. The global annual production of plastic is still increasing at an exponential rate, although it has slowed down slightly from 100% increase in the 70's to 50% in the 2000's (Figure 1). The cumulative production has, however, nearly doubled every decade since 1980.

Furthermore, even if we were able to stop the inputs of plastics to marine environments entirely, an enormous source of microplastics still remains; the macroplastics already in the oceans. These are slowly, but continuously, degrading to smaller and smaller fragments, yet not mineralizing. In an estimation of the total amount of floating plastic debris, macroplastic accounted for 87% of the mass. Sooner or later, all of this will fragment to microplastics, and it is therefore reasonable to assume that an ever increasing accumulation of microplastics will continue for centuries to come.

There is substantial evidence that great quantities of plastic waste cannot be accounted for in marine environments. It has recently been estimated that a total of 270 000 tons of plastic particles are afloat at sea. In comparison, Jambeck et al., estimated that 8 million tons of plastic entered the ocean in 2010 alone, representing 3% of the global production that year. Furthermore, it is believed that all the conventional plastic that has ever entered the ocean still persists. If we assume that a similar proportion of the plastic produced each year since 1950 has reached the ocean, this would constitute 200 million tons in total. This is almost 3 orders of magnitude higher than the estimate for floating plastic debris. Even if these estimates are inaccurate, this must still mean that the vast majority of plastic debris is somewhere else than at the ocean surface.

Measurements of plastic concentrations at the ocean surface over time support this. These have shown no strong temporal trends, even though we have no reason to believe that the inputs of plastic waste has ceased. This also indicates that the ultimate fate of buoyant microplastics perhaps is not at the ocean surface. Fouling

organisms and entrainment in settling detritus could cause sinking, significant amounts could be stranded on shorelines or ingested by organisms. Microplastics have been detected in seabed sediments, watercolumn, shores and organisms. However, the data is limited (particularly for seabed sediments and watercolumn) and it is therefore still uncertain where the majority of plastics end up. This uncertainty about the ultimate fate of plastics in marine environments is a cause for concern.

Some of the "missing" plastic, might also be so small that it goes undetected. When sampling for microplastics in seawater, nets with a mesh size of 0,33 mm is typically used. Therefore, the smaller ranges of microplastics are underreported.

The extent of the effects microplastics have on marine biota is also an issue dominated by uncertainty. We do however know that the small size of microplastics makes them available to a wide variety of organisms, large and small. It has been established both experimentally and in the field that a large number of species ingest microplastics. In addition, exposure routes such as uptake via gills, trophic transfer, adherence to organism surface and translocation have been reported.

So far, only few field studies have attempted to investigate the impacts of microplastics on marine organisms, and these have only focused on the larger sizes of microplastics in birds and fish (GESAMP, 2015). Consequently, there is a large degree of uncertainty about the current effects of microplastic on marine biota. This does not, however, mean that they can be ruled out. On the contrary, adverse effects on biota can easily go unnoticed because of the size of the ocean and our lack of control of what goes on there.

In contrast, several laboratory studies have indicated that microplastic exposure can have a negative impact on organisms. These studies have focused on microplastic mediated transfer of harmful chemicals (both leaching of additives and adsorbed pollutants), internal and external blockages, translocation and accumulation in organisms.

Laboratory experiments have shown that microplastic mediated transfer of chemicals does occur. It is however uncertain how important this transfer is, relative to natural path at current concentrations. But considering the uncertainty about what the current concentrations might be in some locations, and the fact that they are probably increasing, this possible threat should not be ignored. In fact, areas where plastic fragments outnumber plankton have already been reported. Net tows performed in the central North Pacific gyre revealed the astounding figure of six kilos of plastic fragments for every kilo of zooplankton (Moore et al., 2001). In environments like this, the transfer of harmful chemicals from microplastics could be significant.

When exposed to microplastics, a reduction in feeding activity has been demonstrated both for zooplankton and lugworms in separate experiments. In the zooplankton, microplastics were found clustered in the alimentary canal. In these experiments, however, the organisms were exposed to very high concentrations of

microplastics before any effect was observed. Nonetheless, it gives further incentive to try to prevent the ongoing increase in microplastic concentrations.

Laboratory experiments have also shown that microplastics adsorbed to the surface of algae, hindering photosynthesis and promoting oxidative stress. These findings should represent a primary concern, because any impact on the base of the food chain could have alarming consequences. Negative effects on the photosynthesis of primary producers, combined with the effects on the health and function of secondary producers, could potentially result in a reduced productivity of the entire ecosystem.

Only in the last decade the interest in microplastics as an environmental problem has increased significantly, both in the scientific community and in media. The ongoing work to lessen the knowledge gaps is therefore headed in the right direction. For instance, geographical sampling of microplastics is getting more extensive, estimates of the amounts and distribution of them are getting better and the number of studies attempting to investigate the potential harmful effects of microplastics are increasing.

However, the knowledge gaps are still numerous and challenging. In my opinion, further research should be focused on:

- Investigating potential harmful effects of microplastics on more species of marine biota.
- Finding out if there are accumulation zones beyond those found on the ocean surface.
- Establishing the degradation rates of the most common types of plastic in different marine environments.
- Developing methods to retrieve microplastics from the ocean.
- Improving plastic waste management.

Conclusions

The threats that microplastics pose to marine biota are still in the characterization phase due to knowledge gaps both when it comes to exposure levels and established effect levels. However from the information currently available, the following can be concluded:

- Since mass production of plastic commenced in the 1950s an enormous quantity of plastic waste has reached marine environments. Because of the escalating growth in annual plastic production and its persistency, the total amount of microplastics in marine environments can be expected to increase.
- As a result of continuous fragmentation, the number of microplastics are likely to increase even if all inputs were to cease immediately. Particle concentrations are also likely to increase with decreasing size.
- Microplastics are globally distributed, having been reported in all kinds of marine environments from the Arctic to Antarctic. They accumulate in certain areas, such as subtropical ocean gyres and close to population centers. The fate of the majority of microplastics is however still uncertain.
- Microplastics are bioavailable to a wide range of organisms due to their small size, and field studies have demonstrated that microplastics are ingested by a large variety of marine biota of various trophic levels.
- Few field studies have attempted to investigate the impacts of microplastic on marine organisms, representing a huge knowledge gap.
- Adverse effects of microplastic exposure have, however, been demonstrated in laboratory experiments. Of these, the negative impact on the base of the food chain represents a primary concern.

The conclusions listed above give good reason for concern, and the prevailing uncertainty clearly demonstrates the need for further research. This uncertainty riddling every aspect of the problem, also makes it impossible to assess whether or not microplastics are a threat to marine biota. However, there are many indications that they might be, and it can definitely not be ruled out. This, combined with the fact that microplastics are so irretrievable from marine environments underlines the urgency of acting now.

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