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Microplastics in the marine environment

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ABSTRACT

This review discusses the mechanisms of generation and potential impacts of microplastics in the ocean environment. Weathering degradation of plastics on the beaches results in their surface embrittlement and microcracking, yielding microparticles that are carried into water by wind or wave action. Unlike inorganic fines present in sea water, microplastics concentrate persistent organic pollutants (POPs) by partition. The relevant distribution coefficients for common POPs are several orders of magnitude in favour of the plastic medium. Consequently, the microparticles laden with high levels of POPs can be ingested by marine biota. Bioavailability and the efficiency of transfer of the ingested POPs across trophic levels are not known and the potential damage posed by these to the marine ecosystem has yet to be quantified and modelled. Given the increasing levels of plastic pollution of the oceans it is important to better understand the impact of microplastics in the ocean food web.

Contents

1. Introduction

The first reports of plastics litter in the oceans in the early 1970s (Fowler, 1987; Carpenter et al., 1972; Carpenter and Smith, 1972; Coe and Rogers, 1996; Colton and Knapp, 1974) drew minimal attention of the scientific community. In the following decades, with accumulating data on ecological consequences of such debris, the topic received increasing sustained research interest. Most studies have focused on the entanglement of marine mammals (Laist, 1997), cetaceans (Clapham et al., 1999) and other species (Erikson and Burton, 2003) in net fragment litter and on 'ghost fishing' by derelict gear in the benthos (Bullimore et al., 2001; Tschernij and Larsson, 2003). Ingestion of plastics by birds (Mallory, 2008; Cadee, 2002) and turtles (Mascarenhas et al., 2004; Bugoni and Krause, 2001; Tomas and Guitart, 2002) is extensively documented worldwide and at least 44% of marine bird species are known to ingest plastics (Rios and Moore, 2007) with verified accounts of species such as the black-footed albatross feeding plastics granules to its chicks. With recent reports on the unexpectedly high incidence of plastic debris in the North Pacific gyre (Moore et al., 2001, 2001a, 2002; Moore, 2008) this interest has culminated in defining the topic as a high-priority research area in Marine Biology (Derraik, 2002; Page and McKenzie, 2004; Arthur et al., 2009). A particular concern is the occurrence of smaller pieces of plastic debris including those not visible to the naked eye, referred to as microplastics, in the world's oceans. This review attempts to address the fate of plastics in the marine environment, the mechanisms by which microplastics are derived from marine debris and the potential ecological impacts of microplastics.

1.1. Plastics used in the marine environment

The annual global demand for plastics has consistently increased over the recent years and presently stands at about 245 million

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tonnes. Being a versatile, light weight, strong and potentially transparent material, plastics are ideally suited for a variety of applications. Their low cost, excellent oxygen/moisture barrier properties, bio-inertness and light weight make them excellent packaging materials. Conventional materials such as glass, metal and paper are being replaced by cost effective plastic packaging of equivalent or superior design. Nearly a third of the plastic resin production is therefore converted into consumer packaging material that include disposable single-use items commonly encountered in beach debris (Andrady, 2003). How much of the 75–80 million tonnes of packaging plastics used globally each year ends up in the oceans, has not been reliably estimated.

Several broad classes of plastics are used in packaging: Polyethyelene (PE), Polypropylene (PP), Polystyrene (PS), Poly(ethylene terephthalate) (PET); and Poly(vinyl chloride) (PVC). Their high-volume usage is reflected in their production figures given in Table 1 and consequently these in particular have high likelihood of ending up in the ocean environment. Extensive fishing, recreational and maritime uses of the ocean, as well as changing demographics favoring immigration to coastal regions, will increase the future influx of plastics waste into the oceans (Ribic et al., 2010). Land-based sources including beach littler contributes about 80% of the plastic debris. The entire global fishing fleet now uses plastic gear (Watson et al., 2006) and some gear is invariably lost or even discarded carelessly at sea during use. Polyolefins (PE and PP), as well as nylons are primarily used in fishing gear applications (Timmers et al., 2005; Klust, 1982). About 18% of the marine plastic debris found in the ocean environment is attributed to the fishing industry. Aquaculture can also be a significant contributor of plastics debris in the oceans (Hinojosa and Thiel, 2009). The rest is derived largely from land-based sources including beach litter. Virgin resin pellets, a common component of debris, enter the oceans routinely via incidental losses during ocean transport or through run-off from processing facilities (Gregory, 1996; Doyle et al., 2011; Ogata et al., 2009).

Quantifying floating plastic debris (generally using surface-water collection of debris with neuston nets) seriously underestimates the amounts of plastics in the ocean as those in the sediment and mid-water are excluded by the technique. The visibility of debris as flotsam requires plastics to be positively buoyant in sea water (specific gravity of sea water is ~1.025). However, as seen from Table 1 only a few of the plastics typically used in the marine environment has a specific gravity lower than that of seawater. (The specific gravities given are for the virgin resins; plastics in products are often mixed with fillers and other additives that may alter their specific gravity.) Denser varieties of plastics such as nylons tend to submerge in the water column and even reach the coastal sediment.

1.2. Microplastics in the oceans

A recent significant finding is that minute fragments of plastic debris, termed microplastics, occur in oceans worldwide (Barnes et al., 2009) including even in Antarctica (Zarfl and Matthies, 2010). Microplastics, a form of man-made litter, have been accumulating in the oceans for at least over the last four decades (Thompson et al., 2004, 2005). Sampled from surface waters or from beach sand this fraction of litter includes virgin resin pellets, compounded masterbatch pellets and smaller fragments of plastics derived from the larger plastic debris (Moore, 2008).

The term 'microplastcs' and 'microlitter' has been defined differently by various researchers. Gregory and Andrady (2003) defined microlitter as the barely visible particles that pass through a 500 μm sieve but retained by a 67 μm sieve (~0.06–0.5 mm in diameter) while particles larger than this were called mesolitter. Others (Fendall and Sewell, 2009; Betts, 2008; Moore, 2008), including a recent workshop on the topic (Arthur et al., 2009) defined the microparticles as being in the size range <5 mm (recognising 333 μm as a practical lower limit when neuston nets are used for sampling.) Particles of plastics that have dimensions ranging from a few μm to 500 μm (5 mm) are commonly present in sea water (Ng and Obbard, 2006; Barnes et al., 2009). For clarity, this size range alone is referred to as 'microplastics' here; the larger particles such as virgin resin pellets are referred to as 'mesoplastics' after Gregory and Andrady (2003). Persistent organic pollutants (POPs) that occur universally in sea water at very low concentrations are picked up by meso-/microplastics via partitioning. It is the hydrophobicity of POPs that facilitate their concentration in the meso-/microplastic litter at a level that is several orders of magnitude higher than that in sea water. These contaminated plastics when ingested by marine species presents a credible route by which the POPs can enter the marine food web. The extent of bioavailability of POPs dissolved in the microplastics to the biota (Moore, 2008) and their potential bio-magnification in the food web (Teuten et al., 2007) has not been studied in detail.

Unlike larger fragments microplastics are not readily visible to the naked eye; even resin-pellets (mesoplastics) mixed with sand are not easily discernible. Net sampling does not of course collect the smaller microplastics and no acceptable standard procedure is presently available for their enumeration in water or sand. The following is only a suggested procedure derived from published reports as well as personal experience of the author.

Water samples are filtered through a coarse filter to remove mesolitter. Sediment or sand samples are slurried in saline water to allow microplastics to float to the surface. A mineral salt may be dissolved in the collected sea water or slurry sample to increase the water density sufficiently to float plastic fragments. Samples of surface water with floating microparticles are carefully removed for study. Concentrating samples of sea water samples by evaporation can also concentrate the microplastic litter at the surface. Microplastics in surface water samples can be visualised under a microscope using a lipophilic dye (such as Nile Red) to stain them (Andrady, 2010). The water samples will also contain microbiota such as plankton of the same size range but these will not be

Table 1
Classes of plastics that are commonly encountered in the marine environment.

Plastic Class		Specific Gravity	Percentage production[#]	Products and typical origin
Low-density polyethylene	LDPE LLDPE	0.91–0.93	21%	Plastic bags, six-pack rings, bottles, netting, drinking straws
High-density polyethylene	HDPE	0.94	17%	Milk and juice jugs
Polypropylene	PP	0.85–0.83	24%	Rope, bottle caps, netting
Polystyrene	PS	1.05	6%	Plastic utensils, food containers
Foamed Polystyrene				Floats, bait boxes, foam cups
Nylon	PA		<3%	Netting and traps
Thermoplastic Polyester	PET	1.37	7%	Plastic beverage bottles
Poly(vinyl chloride)	PVC	1.38	19%	Plastic film, bottles, cups
Cellulose Acetate	CA			Cigarette filters

[#] Fraction of the global plastics production in 2007 after (Brien, 2007).