Integrated Environmental Assessment and Management — Volume 3, Number 4—pp. 559–566

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MICROPLASTIC—AN EMERGING CONTAMINANT OF POTENTIAL CONCERN?

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Introduction

Global plastic production is now estimated at 225 million tons per year (Plastic-Europe 2006). Plastic debris is accumulating in terrestrial and aquatic habitats worldwide. This debris is progressively fragmenting into smaller pieces. As the plastic breaks down, the potential for ingestion by animals increases. The biological consequences of macroplastic (≥5 mm) debris on wildlife have been well documented and include suffocation, entanglement, and starvation. However, the potential impacts of microscopic (<1 mm) plastic debris remain poorly understood.

What are the sources of microplastic to the environment?

The 2 most likely sources of microplastic are from fragmentation of larger plastic items and the use of small particles of plastic as abrasive scrubbers in cleaning products. Plastics fragment in the environment as a consequence of photolytic, mechanical, and biological degradation. During photodegradation, sunlight oxidizes the chemical structure, causing bond cleavage that reduces the molecular mass of polymers, and as a result plastics become brittle and disintegrate, giving rise to tiny fragments. Within the marine environment, plastics also fragment through the combined effects of wave action and abrasion from sediment particles. In addition, some plastics are susceptible to biodegradation by bacteria and fungi (Gregory and Andrady 2003). Regardless of the method of deterioration, the size and identity of plastic fragments found in marine habitats clearly indicate that microscopic particles can form from the breakdown of larger items. Recent work in the Tamar Estuary (UK) has shown that the size frequency of plastic debris on the strandline is highly skewed toward smaller debris and that, in terms of abundance, microscopic fragments account for over 80% of the stranded plastic (Figure 1c; MA Browne, T Galloway, and R Thompson, unpublished data). Furthermore, microscopic fragments of materials used for clothing (polyester, acrylic), packaging (polyethylene, polypropylene), and rope (polyamide) have also been identified from beaches around the United Kingdom (Thompson et al. 2004).

Another source of microplastic particles is from industrial and domestic products, including toilet, hand, body, and facial cleansers (Derraik 2002; Thompson et al. 2004), that contain tiny polyethylene and polystyrene particles less than 1 mm in

diameter. In addition, larger particles of acrylic, melamine, and polyester, ranging from 0.25 to 1.7 mm in diameter, are used to clean machinery and boat hulls in dockyards by a process known as "media blasting." Microplastic particles are also used in a range of medical applications, including drug delivery systems. Small particles from all these sources are likely to be transported with wastewater and through sewage treatment works and subsequently enter aquatic habitats. Hence, there is considerable potential for microscopic plastic debris to accumulate in freshwater and marine environments.

What is the extent of microplastic contamination in habitats?

A study of archived plankton samples from the northeast Atlantic showed that the abundance of microscopic plastics in the water column has increased considerably over the last 40 y, and this trend mirrors the global rise in plastic production (Figure 1b). Similar particles were also found on beaches throughout the United Kingdom, and therefore microplastic particles appear to be a widespread contaminant that has accumulated across a range of habitats (Thompson et al. 2004). Recent work on plastic debris found within the Tamar Estuary (UK) has identified acrylic, polyamide, polyethylene, poly(ethylene: propylene), polyester, polyethylene terephthalate, polybutylene terephtalate, polyoxylmethylene, polypropylene, polystyrene, polyurethane, and polyvinylchloride (M.A. Browne, T. Galloway, and R. Thompson, unpublished data). Since only fragments that differed in appearance from sediment grains or plankton were quantified, the amount of microplastic recorded in this study is likely to represent only a small proportion of the microscopic plastic in the environment. Further research is required to optimize identification methods using Fourier transform infrared spectroscopy so that the abundance and composition of all microplastic can be assessed quickly and efficiently.

Do animals ingest microplastic?

Large (>5 mm) plastic debris is frequently ingested by a range of species, including fish, turtles, birds, and cetaceans (Derraik 2002). Microplastic is much smaller, occupying the same size range as plankton. Hence, there is a greater potential for ingestion by a wide range of animals. Uptake of microplastic by different feeding guilds will depend on the size, shape, and density of the particles, as these parameters determine the position of the debris in the water column and potential availability. For a given size, low-density plastic will float and will be available for uptake by filter feeders or planktivores, whereas high-density plastics, such as polyvinyl chloride (PVC), will tend to sink and accumulate in sediments where they are more likely to be ingested by deposit feeders.

The uptake and retention of microplastic by animals in their natural habitats has received little attention, partly because quantifying tiny plastic fragments in the tissues of animals presents a range of methodological problems. Laboratory trials have shown that amphipods (detritivores), barnacles (filter feeders), and lugworms (deposit feeders) ingest small PVC plastic fragments (mean size 230 µm; Thompson et al. 2004). In addition, filter-feeding polychaetes, echinoderms, bryozoans, and bivalves have been shown to ingest 10-µm polystyrene microspheres during feeding assays (Ward and Shumway 2004). Recently, mussels (*Mytilus edulis*) have been show to ingest and accumulate polystyrene beads as small as 2 µm in their gut cavity (Figure 1d). Given that microplastic is accumulating in the environment, these laboratory trials suggest that microplastic particles are probably also being ingested by organisms in their natural habitats.

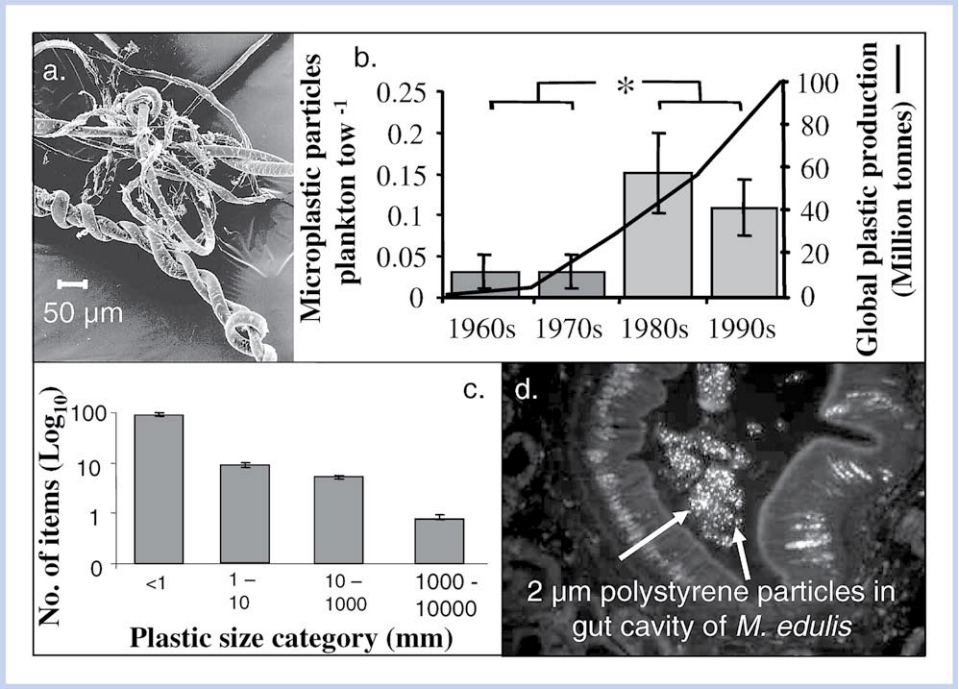

Figure 1. (**a**) Electron micrograph of microplastic fiber from the shoreline. (**b**) Accumulation of microplastic in the water column in the northeast Atlantic, with the global plastic production figures for the same period superimposed for comparison (adapted from Thompson et al. 2004). (**c**) Size composition of plastic debris in Tamar Estuary, United Kingdom (note log scale; unpublished data) (**d**) Tissue section of the gut of *Mytilus edulis* containing 2 µm fluorescent polystyrene particles (365-nm excitation, 477-nm emission) ingested during a laboratory trial (M.A. Browne, T. Galloway, and R. Thompson, unpublished data).

If ingested can microplastic transfer from the gut to the other body tissues?

Once microplastic is ingested by animals, it may be retained in the digestive tract, egested in the form of feces, or absorbed into the epithelial lining of the gut by phagocytosis. Retention of larger plastic debris certainly occurs in the digestive tracts of seabirds and mammals. Laboratory trials using lugworms (*Arenicola marina*) kept in sediments containing microplastic have shown that these animals are capable of egesting this debris within their fecal casts. If microplastic particles are taken up by the gut epithelial lining, then further transport around the body is possible. Qualitative research in rodents has shown that solid polystyrene microspheres can readily transfer (translocation) from the gut to the lymphoid system (Hussain et al. 2001). The lymphoid system supplies the circulatory system, and hence these particles will then have the potential to be transferred to other tissues around the body. Given that the rodent digestive system is similar to many other organisms, translocation of ingested microplastic from the gut around the body of aquatic animals is likely. Indeed, recent laboratory trials involving mussels (*M. edulis*) have shown that ingested polystyrene microspheres can translocate from the gut cavity to the hemolymph within 3 d (M.A. Browne, T. Galloway, and R. Thompson, unpublished data).

Does ingestion of microplastic have any toxicological consequences for animals?

A wide range of vertebrates and invertebrates have been shown to ingest and accumulate plastic debris; however, little is known about the biological effects. Micro- and nanoscopic (<1 µm) plastic and nonplastic particles exert damage through the combined effect of their intrinsic toxicity and their large surface area. For example inhalation of PVC dust by humans can cause, depending on monomer composition and size, lung and liver damage through tissue fibrosis and cancer (Wagoner 1983).

Polymers are composed of repeating subunits called monomers. Polyvinylchloride (Marcilla et al. 2004), polystyrene (Garrigos et al. 2004), and polycarbonate (vom Saal and Hughes 2005) have been shown to release toxic monomers that are linked with cancer and reproductive abnormities in humans, rodents, and invertebrates. Monomers are not the only chemicals that could be potentially transferred from plastics upon uptake by organisms. During manufacture, a range of chemical additives are incorporated into plastic, including catalysts (organotin), antioxidants (nonylphenol), flame retardants (polybrominated diphenyl ethers), and antimicrobials (triclosan). In addition to chemicals used in manufacture, plastic has been shown to adsorb and concentrate hydrophobic contaminants, including polychlorinated biphenyls, dichlorodiphenyl trichloroethane, and nonylphenol, from the marine environment at concentrations several orders of magnitude higher than those of the surrounding seawater (Mato et al. 2001). If plastics are ingested, they could act as a mechanism facilitating the transport of chemicals to wildlife. This may be particularly relevant for microplastics since they will have a much greater ratio of surface area to volume than larger items and hence are likely to have greater potential to transport contaminants.

Conclusion

Given the rapid rise in plastic production, the disposable nature of many plastic items and the durability of plastic, contamination of the environment by microplastic is likely to increase. Laboratory trials have shown that organisms with a range of feeding strategies are capable of ingesting and accumulating microscopic particles. More work is now required to determine the potential toxicological consequences of this new form of contamination.

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A CALL FOR SCIENTIFIC RIGOR IN THE DEVELOPMENT OF CRITICAL BODY RESIDUES: A CASE STUDY

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Tissue residue–response relationships are increasingly used in ecological risk assessments (ERAs) and natural resource damage assessments (NRDAs) to predict the toxicological consequences of accumulated chemical body burdens. Given that chemical body burden provides an integrated measure of exposure for certain chemicals, the use of these data as the dose metric in the overall risk equation is both practical and scientifically supportable in some situations. The utility of these data to reliably assess toxicological response is, however, tightly tied to the availability of data that reliably characterize the exposure–response relationship and can be used to establish a critical body residue (CBR) associated with a specified level of effect. We believe that scientific rigor and a sound toxicological understanding are necessary to develop reliable dose–response metrics based on body burden. CBRs developed without that foundation are not reliable and should not be used.

Meador (2006) reviewed several key technical issues to consider when using toxicological data to derive CBRs for aquatic species. While we don't agree with Meador's (2006) suggestion to use CBRs to derive sediment quality guidelines,