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POSTNOTE

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Marine Microplastic Pollution

Plastic pollution is accumulating rapidly in the world's oceans. The potential effects of microplastics on the environment and human health are an area of active research. This POSTnote summarises their sources and spread, the evidence that they present a risk and possible strategies to reduce plastic pollution.

Overview

- Microplastics, plastic pieces under 5 mm in size, are a widespread ocean contaminant.
- Sources of microplastic include fibres from synthetic textiles, microbeads from cosmetic and industrial applications and large items of plastic debris that break down into smaller pieces.
- Studies have shown the presence of microplastics in seafood. The potential risk to human health is little studied and remains uncertain.
- Laboratory evidence suggests that microplastics and their associated additives can be harmful to wildlife. However, not all species or life stages may be affected.

Background

Plastic is an extremely versatile resource whose production levels have increased dramatically since the 1950s.[1] It can be made into a wide range of products that are strong, durable, inexpensive and lightweight. However, some of the properties of plastic that make it such an attractive material during use also make it problematic when it becomes waste. The primary issue is that it is highly resistant to degradation. Indiscriminate discarding and the accidental release of plastic into the marine environment has resulted in the rapid accumulation of persistent marine plastic debris in the world's oceans. By weight, most of this consists of large pieces of debris such as fishing gear, bottles and plastic bags; but by number, the dominant type of debris in the world's oceans are small pieces that are under 5 mm in size – these are known are microplastics.[2] It has been estimated that there were between 15 to 51 trillion microplastic particles floating on the surface of the world's oceans in 2014, weighing between 93 and 236 metric tons.[3]

Sources and Spread

Microplastics can either be manufactured (for example, as microbeads for use in cosmetic scrubs, toothpastes, and cleaning products), or can result from the fragmentation of larger items of plastic debris. They are ubiquitous throughout the marine environment and have been found in estuaries, lakes, coasts, sediments, the open ocean, deep seas, and arctic sea ice.[4-9]

Sources

It is frequently possible to identify what type of plastic polymer (Box 1) a particular piece of ocean debris is made of, regardless of its size. However, when pieces become small, fragmented and degraded they are almost impossible to trace to their original source. As a result, the relative importance of different microplastic sources is unknown. The three largest sources are thought to be fibres from textiles, microbeads and large pieces of plastic debris,[10] which will become microplastics as they fragment and degrade. However, a 2014 report by the Norwegian Environment Agency also highlighted the potential importance of microplastic emissions from normal wear and tear of plastic products such as tyres, fishing nets, rope and carpets, as well as plastics in paints and varnishes.[11]

Fibres

Small fibres from synthetic clothing, such as polyester and nylon, are released into waste water through the process of washing clothes.[12] Waste water treatment plants are not designed to retain microplastics, and the resulting sewage effluent can carry fibres out to rivers, lakes, estuaries and the sea. Fibres are commonly the most abundant type of microplastic found in marine wildlife and sediments.[7,13-16]

Microbeads

Microbeads are small spheres or fragments of plastic that are used in cosmetics, household cleaning products and industrial blasting. They include beads used in exfoliants

Box 1. Types of Plastic

Plastics are made from a group of large molecules known as polymers. Polymers come in numerous forms, which vary in characteristics such as buoyancy, toxicity, and degradability. Although there are thousands of types of polymers, most plastics are made from one of six: polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyurethane (PUR) and polyethylene terephthalate (PET).[17] Plastics may also contain additives that are designed to change the properties of the end product; such as stabilisers, flame retardants and pigments. Some additives slow down the degradation rate of plastics and have the potential to leach out into the environment.

Biodegradable plastics degrade more rapidly than conventional plastics under certain environmental conditions. For a product to be labelled as biodegradable, it should meet one of a number of recognised standards for the extent of degradation required under a given time period.[18] However, current standards refer to rates of degradation that would only occur in an industrial composter, where temperatures reach 70°C. There is no technical standard that would require biodegradable plastic to degrade fully within a relevant time frame in the marine environment.

and toothpastes, as well as beads used in 'media blasting', where small plastics and other granules such as sand are propelled onto the surfaces of buildings, machinery and boats. In the UK, emissions of microplastics into the environment have been estimated at between 16-86 tonnes per annum from facial exfoliants alone.[19] There are no academic estimates of the number of particles that are entering the ocean as a result of media blasting.

Large Plastic Debris

Large pieces of plastic can enter the ocean as a result of littering or accidental escape from waste management systems. This can occur at sea, for example through the accidental or deliberate disposal of fishing gear, but marine litter can also originate from inland sources and enter the marine environment after it has travelled down rivers, or be carried in by the wind. Some definitions of large plastic debris also include pre-production pellets that are known as nurdles, but because they are usually around the 5 mm size mark, several studies list them as a type of microplastic. They are potentially a large source of plastic pollution,[11] though there are no robust figures estimating the rate at which pellets are lost at sea or at processing plants.

The importance of different sources of large plastic debris depends on whether it is the number or weight of items that is measured. For example, 891 visual surveys that counted the number of large plastic items on the surface of the world's oceans found that 20% of items were fishing-related debris, 58% were non-fishing related items and 22% were classified as miscellaneous.[2] However, by weight, fishing gear was the dominant form of litter observed, accounting for 70% of the total. Most of this (58%) was derelict fishing buoys. Just over a quarter of non-fishing gear items were pieces of foamed polystyrene, followed by bottles (18% of all non-fishing items), and plastic bags/films (10%). Data on the composition of plastic debris that has sunk to the bottom of the ocean or is suspended in the water column is limited.

Filtering Microplastics from Waste Water

There is little information on how efficient waste water treatment plants are at capturing microplastics before they enter the environment. Studies across eight European treatment plants have found that the percentage of microplastic particles captured in sewage sludge ranges from 24% to 100%, depending on the type of microplastic, treatment process and methodology used in the study.[20] However, these studies are limited in scope, and in cases where waste water bypasses treatment no microplastics may be filtered out (for instance, if it is released directly into the environment as a result of sewage overflow). Plastic particles in sewage sludge that has been used as fertiliser may additionally enter the sea at a later date as a result of surface water run-off from agricultural land.

Areas of High Concentrations

Plastic pollution is moved around the world's oceans by currents and prevailing winds. Large differences in the number of microplastic particles reported at different locations suggests that their spread is uneven. Several studies have modelled the spread of microplastics through the marine environment, but predicting these movements is complex and limited by uncertainties, including:

- how the size, shape, density and fragmentation rate of different types of plastic affect movement
- how buoyancy is affected by the accumulation of algae and bacteria on the plastic's surface
- the proportion of microplastics that are ingested by wildlife or end up in sediments (including beaches).

Models and field studies agree that buoyant plastics are likely to accumulate in areas of the ocean with circular currents that are known as sub-tropical gyres.[21-24] These are where the five oceanic 'garbage patches' occur. However, concentrations can vary by a factor of ten across very small distances,[23] and also tend to be much higher close to densely populated coastal areas.[12]

Monitoring Microplastics

Most estimates of microplastic abundance are based on particles collected from plankton nets with a mesh size of 330 µm (1 µm = 1 thousandth of a mm), which means that microplastics smaller than this threshold are less likely to be collected and counted in samples. However, several studies have shown that smaller microplastic particles do exist in the ocean,[25] and have the potential to become nanoplastics measuring less than 100 nm (1 nm = 1 millionth of mm).[26] As there is no routine sampling method for particles of this size, it is likely that figures for the amount of marine microplastics in the ocean are underestimates.

Current monitoring of microplastic pollution is not standardised. Studies use a range of sampling techniques and have different definitions of how small a fragment needs to be in order to be classed as a microplastic. The Joint Programming Initiative on Oceans – an EU funded initiative to pool research efforts – includes funding for a project to standardise methods for microplastic analysis.

Risks to Wildlife and Human Health

The small size of microplastics means that they can be ingested by marine life. They have been found in a variety of species including zooplankton, mussels, oysters, shrimp, marine worms, fish, seals and whales.[16,27-37] Several of these species are of commercial importance. For example, a 2009 survey in the Clyde Sea found that 83% of Norwegian lobster (the most valuable fishery in Scotland) were contaminated with plastic, mainly in the form of fibres.[38] Similarly, trawls in the English Channel found microplastic contamination in 36.5% of fish caught,[32] a proportion similar to that found in fish from the North Pacific Central Gyre, known as the 'Great Pacific Garbage Patch'.

Toxicity to humans and wildlife could potentially be caused by the plastic polymer itself, by the additives it contains (Box 2), or by other chemicals that are known to associate with microplastics once they are in the ocean (Box 3). However, there are a variety of polymers that behave differently according to their size and shape[39] and thousands of different additives used in products. This makes it difficult to make general predictions about the effects of ingesting them. Little is known about the rate at which plastic additives leak into their surrounding environment (whether this be the ocean or biological tissues), as well as the potential levels of exposure for humans and wildlife.

Human Health

No studies have investigated whether microplastics that are unintentionally ingested by humans can be subsequently transported into tissues.[40] Several studies show that microplastics are present in sea food sold for human consumption,[15,16,28,29,41] including mussels in North Sea mussel farms and oysters from the Atlantic. Although the gut wall may be an important barrier,[40] there is a possibility that very small particles such as nanoplastics could penetrate gut tissues. Experiments in rats have showed that polystyrene microspheres of 50-100 nm can be absorbed into the body through the gut and transported to the liver and spleen.[42] The ability of different plastics to enter tissues is likely to depend on their size and chemical properties. Once inside, there are number of ways in which nanoplastics could theoretically interact with biological tissues in a way that could be toxic; but these have not been tested, and the risk to human health remains unknown.[40]

Wildlife

Laboratory experiments have shown that plastic ingestion can have detrimental effects in a range of species that have key roles in marine ecology, though some of these experiments expose animals to higher concentrations of microplastics than those that have been reported in sediments and the water column. The magnitude of effects varies between species, and some animals appear to be affected only at certain stages of their lifecycle (Box 4). Field studies in this area face several difficulties. Wildlife in the marine environment is exposed to a wide range of other pressures, including rising temperatures, ocean acidification and other types of pollutants such as heavy metals. Disentangling the effects of microplastics from the effects of these other factors will be challenging.

Box 2. Effects of Additives

Some additives that are incorporated into plastics during the manufacturing process, including bisphenol A (BPA), phthalates and brominated flame retardants, are known hormone disruptors.[43-45] Studies have found that exposure to BPA at levels found in the general population can be associated with the onset of obesity, cardiovascular disease, increases in hormonally-mediated cancers and changes in behavioural development.[46] All plastics, especially those in packaging, undergo rigorous testing to ensure that levels of toxic chemicals are kept below defined levels; but the behaviour of plastics and additives in the sea and potential levels of exposure are still being investigated. Items made from PVC and printed polyethylene bags appear to have the highest potential to leach additives into seawater.[47] The risk of exposure to additives such as BPA through marine microplastics is considered low compared to other sources.[48]

Environmental Effects

There are several concerns over the potential ecological effects of microplastics that are not related to the ingestion of these particles by animals or algae. Examples include:

- Pieces of microplastic can provide a surface on which marine insects can lay their eggs. The number of marine pond skaters has been shown to increase with growing amounts of microplastics in the North Pacific.[49] Such proliferation of species that were previously limited by the scarcity of places on which to lay their eggs has unknown ecological consequences, but may allow several species to become more abundant and expand their range.
- The community of microbes associated with plastic fragments is different to that normally found in seawater.[50] A study looking at the microbial communities on pieces of polyethylene (the most commonly produced plastic worldwide) and polypropylene (frequently used in packaging) found that of a total of 3,484 species of microbe, only 53 were shared by polypropylene, polyethylene and seawater, whereas 799 were unique to polypropylene and 413 were unique to polyethylene. The ecological consequences of this are also unknown.
- The presence of high concentrations of microplastics in beach sediments can change their permeability and heat absorbance,[51] raising concerns about the effects on species where sex is determined by temperature (e.g. sea turtles) and sediment-dwelling species that would be at a higher risk of desiccation (including worms, crustaceans, and molluscs).

Addressing the Risks of Microplastics

Three policies covering marine plastic litter are outlined in Box 5. In addition, in January 2014 the European Parliament passed a resolution on plastic waste in the environment calling for single use plastics that cannot be recycled (including microbeads) to be phased out.

Box 3. Plastics as Transport for Other Pollutants

The chemical and physical properties of microplastics enable them to attract and accumulate a number of other chemicals in the oceans. These include most persistent organic pollutants (POPs), and persistent bioaccumulative and toxic substances.[52-54] Chemicals on microplastics ingested by an organism can dissociate from plastic particles and enter body tissues. This has been demonstrated in lugworms and seabirds.[52] In the latter case, contaminants were passed to the birds as a result of eating polyethylene resin pellets as well as eating fish that were exposed to contaminants in the water, suggesting that they have the potential to travel through the food chain. However, natural sediments can also attract substances such as POPs, and there is debate over the importance of microplastics as a transmitter of POPs and other substances into tissues compared to other subtrates. There is evidence that certain chemicals preferentially attach to plastic,[53,54] but there are only limited data on the extent to which chemicals dissociate from plastic and migrate into tissues in different environmental conditions and on how quickly they accumulate in the food chain.

Box 4. Effects of Microplastic Ingestion in Laboratory Studies
The effects of microplastics on wildlife that have been found in laboratory studies include:

- Polystyrene microparticles reduced the number and size of eggs produced by **oysters**,[55] but a separate study found no effects on the development or feeding capacity of oyster larvae.[56]
- **Blue mussels** exposed to high concentrations of high density polyethylene (HDPE) grains[57] and polystyrene microbeads[58] absorbed them into tissues through their gills and feeding apparatus. Plastics inside tissues in the polystryrene study caused no measurable harm, but the HDPE study found evidence of an inflammatory response. It is unknown whether these effects were caused by mechanical abrasion or a toxic effect of the plastic's chemistry.
- **Lugworms** (a key food source for fish and wading birds and an important animal for maintaining the ecology of the seabed) exposed to PVC had 50% lower energy reserves than worms that were not exposed to microplastic.[59] This was probably as a result of reduced feeding activity, inflammation and plastic particles being retained in the gut for long periods of time.
- Copepods (a type of **zooplankton** eaten by several commercially important fish larvae) exposed to polystyrene microbeads produced smaller eggs with reduced hatching success.[60] They have also been shown to produce microbead-laden faecal pellets[61] that can transfer up the food chain.[62] These have been shown to sink at different rates to normal pellets, which could affect the rate of carbon accumulation in marine sediments in regions with high levels of microplastic contamination.[62]
- Exposure to polyethylene pre-production pellets disrupted hormone production in female **Japanese medaka** (a type of fish).[63] Hormone production was also disrupted in males, but in this case the effects were considered to be more likely a result of chemicals that had become associated with the microplastic particles in the ocean rather than the microplastic itself.
- **Periwinkles** kept in water with microplastics collected near Calais in France, at concentrations similar to that found on beaches, altered their behavioural response to cues of the presence of crab predators, increasing the likelihood of their predation.[64]

Preventing Microplastic Marine Pollution

There is widespread agreement that the most effective way to reduce microplastic pollution is to prevent plastic from entering the marine environment in the first place. This applies to pieces that are already small enough to be classed as microplastics, but also to large pieces of debris that will eventually fragment into microplastics. Solutions that aim to tackle these larger pieces will have the additional benefit of reducing the negative social, economic and ecological impacts associated with large plastic debris, such as impacts on mental wellbeing, the entanglement of ship propellers on discarded fishing gear, and the entanglement of wildlife on items like rope and six-pack rings.[65-68] Approaches to preventing plastic pollution include changing the design of plastic products and packaging, improving plastic waste facilities and management, and changing plastic use and littering behaviour through education and public engagement.[17] Preliminary data suggest public awareness of microplastics is low,[17,69] which may be a barrier to changing behaviours. However, there have been no detailed studies investigating public understanding.

In 2014, the overall recovery rate for plastic waste in the UK was 59%, of which 29% was recycled and 30% was incinerated for energy recovery.[1] The plastic bag charge led to a 71% decrease in single-use plastic bag use in Wales (2011-2014),[70] and 80% in Scotland (2014-2015).[71] A widening range of plastic packaging is also being picked up at kerbside collections. A number of NGOs are additionally calling for the implementation of a deposit return scheme (DRS) in Scotland, with a feasibility study published in May 2015.[72] These involve consumers paying a small deposit on drinks bottles that would be refunded when they are returned to a recycling point. However, there has been no systematic policy evaluation at scale,[73] and the available evidence on whether they reduce littering behaviour cost-effectively remains subject to debate.[74]

Box 5. Existing Policies

EU Marine Strategy Framework Directive
Microplastic is listed as a type of marine litter under the EU Marine Strategy Framework Directive. In order to achieve good environmental status by 2020, member states need to ensure that the properties and quantities of marine litter do not cause harm to the coastal and marine environment. Determining these levels is difficult as the amount of microplastic pollution required to do harm is likely to be variable between species, and 'harm' itself has not been defined.

OSPAR
OSPAR (the Oslo and Paris Convention for the Protection of the Marine Environment in the North East Atlantic) has a target (2010-2020) to 'substantially reduce marine litter in the OSPAR maritime area to levels where properties and quantities do not cause harm to the marine environment'. Its system of monitoring plastic debris is based on three indicators: beach litter, seabed litter and plastic found in the stomachs of fulmars (a seabird species). Further indicators, including measuring plastic loads in a range of species, and an indicator for microplastics, are under development.

MARPOL
MARPOL (International Convention for the Prevention of Pollution from Ships) aims to reduce marine pollution from ships. Annex 5 specifically deals with marine litter and prohibits the disposal at sea of all forms of plastic.

The elimination of microbeads found in cosmetics has been the central focus of a number of recent campaigns, including the Marine Conservation Society's *Scrub it out!* and the North Sea Foundation and Plastic Soup Foundation's *Beat the Microbead* (see Briefing Paper 7510). Several countries have issued or are in the process of issuing bans on microbeads in cosmetic products, including Canada and the US. Presently, 25 UK companies are or have stated an intention to become microbead-free, such as the large multinationals Unilever, Colgate-Palmolive and P&G.

Removing Microplastics from the Ocean

Even if the flow of plastic litter into the sea was halted immediately, the amount of microplastic in the ocean would likely continue to increase as larger items already in the ocean fragment and degrade.[17] Technology to remove microplastics from the ocean does not currently exist.[75] However, the UK participates in a number of schemes that are helping to remove existing large debris. An example is Fishing for Litter, a voluntary scheme where participating boats are given large bags to collect litter found in their nets as part of their normal fishing activity. The bags are then collected at participating harbours for disposal or recycling. Over 360 fishing vessels and 26 harbours across Scotland and South West England are participating.[76]

Endnotes
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