

Plastics in Seafood

Greenpeace Research Laboratories, 2016



1. Plastics in the ocean: issue summary

It has been estimated that plastics make up 60-80% of all marine litter (Derraik, 2002).

No definitive figure on the abundance of plastic in the world's oceans exists, but a quantitative theoretical model estimates that there are 5.25 trillion pieces of plastic debris weighing in the region of 268,940 tons floating in the sea, not including pieces on the seabed or on beaches (Eriksen *et al.*, 2014). More recent studies put the estimates even higher, at perhaps more than 50 trillion pieces (van Sebille *et al.*, 2015), though in practice any estimates are impossible to verify with accuracy.

The extent of plastics of all sizes in the marine environment is of particular concern, because of its persistence in the environment and propensity to undergo wide dispersal.

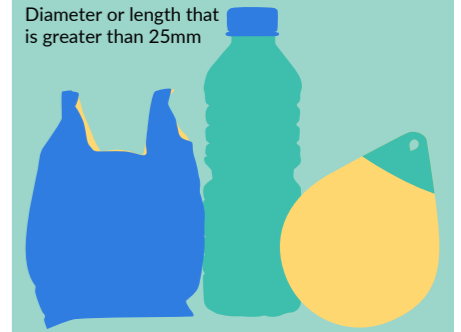
Since the 1960s, anecdotal reports and scientific papers have detailed the effects of large pieces of plastic on birds, fish and marine mammals.

But now there is another concern: 'microplastics'. Microplastics are particles less than 5 mm in diameter or length and could be spheres, fragments or filaments. Microplastics are either primary (they were manufactured that size, such as the pre-production plastic pellets known as 'nurdles') or secondary (macroplastics that have degraded by exposure to wind, waves and ultraviolet light).

MACROPLASTICS

>25mm

Diameter or length that is greater than 25mm



MESOPLASTICS

<25mm

Diameter or length that is between 25mm and 5mm



MICROPLASTICS

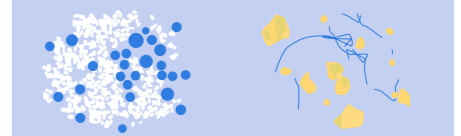
<5mm

Diameter or length that is up to and including 5mm

Can be divided into:

Primary microplastics
plastic particles that were manufactured to be a particular size eg microbeads

Secondary microplastics
pieces of plastic that have been degraded from a large item eg plastic bottle to a smaller size



NANOPLASTICS

<1µm

Considered a subset of microplastics
Diameter or length that is smaller than 1µm

There is currently no formal size definition for microplastics. For the purposes of this report we have adopted the measurements in the GESAMP (2015) report, which states that microplastics are considered to be in the size range 1 µm to 5 mm.

To help raise awareness of the microplastics problem, Greenpeace launched a campaign in spring 2016 to persuade the UK government to ban the use of solid microplastics, including microbeads, in consumer products such as toothpaste, washing powders and facial scrubs. A ban on the use of plastic microbeads was also proposed by the United Nations Environment Programme in its 2015 report 'Plastics in Cosmetics: Are We Polluting the Environment Through Our Personal Care?'



It is the potential impact on the marine environment of microplastics that is attracting the attention of research scientists, governments, charities, consumer groups and environmental organisations.

Plastics production has surged over the past 50 years. In 2013, global production of plastics rose to 299 million tonnes, an increase from 204 million tonnes in 2002; in Europe in 2013, packaging accounted for 39.6% of all plastic use (Plastics Europe, 2015). Many plastic items are intended to be used just once, which is generating a mountain of waste.

Discarded plastic may end up in landfill, be incinerated or recycled. But some ends up in waterways and the ocean through urban drainage, runoff or 'leachate' from landfill sites, through the deliberate dumping of garbage, accidental spillage from ships, or in effluents from sewage and wastewater treatment plants (Derraik, 2002).

Why is so much attention being focused on tiny pieces of plastic? It's because we now know that microplastics in the sea could have an even greater effect than macroplastics.

Carelessly discarded waste plastic can affect marine life through entanglement, choking, strangulation and malnutrition. Because they are so small, microplastics have the potential to be ingested by a greater number of organisms than macroplastics. Microplastics could also adsorb and subsequently desorb toxic contaminants (adsorb is the term used when a plastic attracts a chemical compound that 'sticks' to the plastic; desorption occurs

when the plastic 'releases' the adsorbed chemical) or leach chemicals that have been added during the manufacturing process.

As more plastics are thrown away, more waste can enter the world's water systems. And because large items of plastic degrade into ever smaller pieces, each piece of macroplastic floating at sea can give rise to hundreds, if not thousands, of pieces of microplastic.

Academic research is currently addressing the myriad of issues surrounding microplastics in the ocean. Questions include:

- What is the quantity of microplastics in the ocean?
- Can microplastics accumulate in the food chain?
- What is the physical impact of microplastics on marine organisms?
- What is the fate of plastic following ingestion by marine organisms?
- Do marine organisms actively choose to consume microplastics?
- What is the toxicity of plastics and associated or adsorbed chemical contaminants to humans and marine organisms?

Here, we highlight the latest scientific literature and technical reports relating to microplastics in the marine environment. Specifically, we focus on research concerning fish and shellfish, and consider the potential effects on humans of consuming microplastics-contaminated seafood.



Research challenges:

One of the difficulties in determining the location and quantity of microplastics in marine organisms and seawater lies in extraction and identification protocols. Microplastics are usually collected by net trawls from a boat or by taking samples from beaches, but using tow nets as a sample method could result in sets of data that are difficult to compare. Different tows could collect the lighter, floating plastic and neglect the heavy plastics that sink to the seabed. Correct identification of microplastics can be complex and time consuming, often requiring specialist equipment and laboratory processes; some fibres look like plastic but may in fact be cotton (Song *et al.*, 2015). Other potential problems include the accidental external contamination of a sample of microplastics by plastics on boats, paintwork, trawler nets, or even laboratory air. Standardising the methods in which microplastics are collected, investigated and identified will help research groups to more accurately compare results from different studies.

2. Microplastics in seafood: an overview

The presence of plastic debris in the marine environment is an established global problem and the ingestion of microplastics by marine organisms is widespread.

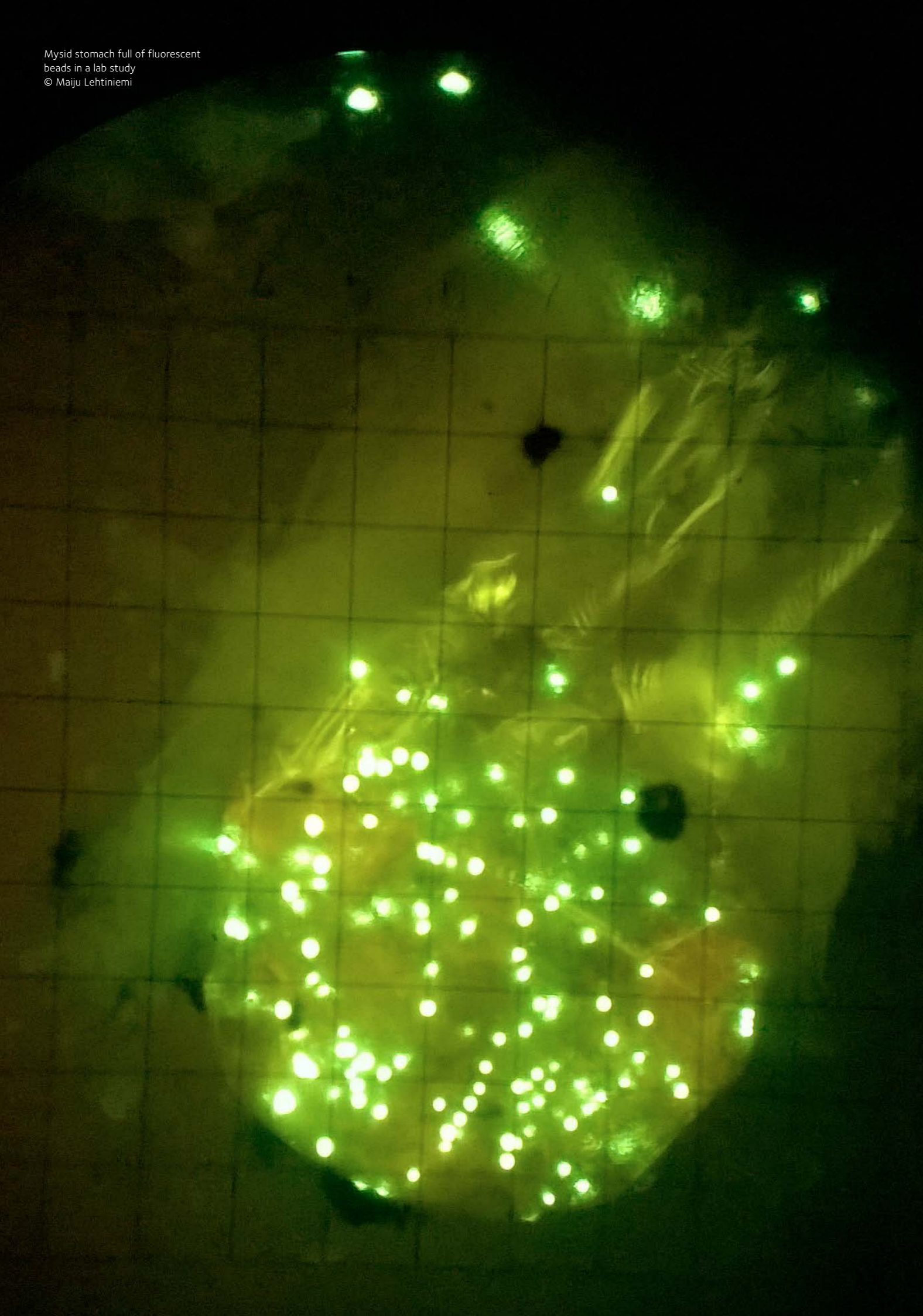
One estimate suggests that at least 170 marine vertebrate and invertebrate species ingest anthropogenic debris (Vegter *et al.*, 2014). However, because the field of microplastics research is relatively new, it is important to note that methods to isolate, identify and record plastic pollution are still being developed and have yet to be standardised (Koelmans *et al.*, 2015).

Quantitative studies to monitor the number of microplastics in the guts of marine-caught fish and shellfish are difficult to carry out (see Box) and have produced varying results. Analysis of field samples that have been published in science journals report zero to 21 microplastics per individual (Lusher *et al.*, 2016; Rochman *et al.*, 2015; Lusher *et al.*, 2013), but these figures are by no means definitive. Now that the presence of microplastics in a number of different marine organisms has been established, scientific research is focusing on the impact of microplastics on marine organisms.

Scientific analysis of tissue from marine organisms has identified polymers including polypropylene, polyethylene, alkyd resin (commonly used in paints and other coatings), rayon, polyester, nylon and acrylic, polyamide, polystyrene, polyethylene terephthalate (PET) and polyurethane (Neves *et al.*, 2015; Rummel *et al.*, 2016).

More studies have been carried out in the Northern Hemisphere to date, particularly in Europe and the United States, than the Southern Hemisphere, though this trend is beginning to change. For example, a study published this year looked at microplastics contamination of mussels harvested from the sea off the coast of São Paulo, Brazil (Santana *et al.*, 2016).

In addition, there are an increasing number of microplastics studies from China being published (Li *et al.*, 2016; Li *et al.*, 2016b). However, there are fewer data from Asia, Africa and the poles. That said, microplastics have been found floating in the waters of the Arctic and Antarctic as well as the Atlantic, Pacific and Indian oceans and in deep-sea sediments, so it is reasonable to conclude that the presence of microplastics in the sea is ubiquitous (GESAMP, 2015).



Field research: Levels of microplastics in seafood

- A Portuguese study found microplastics in 19.8% of 263 commercially caught fish from 26 species (Neves *et al.*, 2015).
- In a field sample, 36.5% of fish caught by trawler in the English Channel contained synthetic polymers. This study did not examine the impact on fish of microplastics ingestion. The authors suggest that ingestion of microplastics was probably by normal feeding activity (Lusher *et al.*, 2013).
- Analysis of 121 individual fish including the commercial species swordfish, Atlantic bluefin tuna and albacore tuna from the Central Mediterranean Sea found plastic debris in 18.2% samples (Romeo *et al.*, 2015).
- A research group based in the USA analysed fish caught in the wild and sold for human consumption at markets in two geographical locations: Makassar, Indonesia, and California, United States. The study found anthropogenic debris in 28% of fish caught in Indonesian waters and in 25% of fish caught in the ocean off the coast of the United States. All debris found in fish from Indonesia was plastic, whereas debris from fish caught in the United States was primarily fibres (the fibre types were not analysed, so could be plastic or cotton) (Rochman *et al.*, 2015).
- Small marine organisms that ingest plastic particles could transfer some or all ingested particles to organisms within the food chain. A field study that collected fish that feed on plankton from the North Pacific Central Gyre found that 35% of collected fish contained plastic fragments. Fish that feed on plankton are prey for other fish in the food web, so plastic contamination could impact predators such as tuna and squid that feed on smaller fish (Boerger *et al.*, 2010).
- In a sample of 290 fish caught from the North Sea and the Baltic Sea, the guts of 5.5% of fish contained plastics. Analysis showed that 40% of the plastics were polyethylene. Other types were polyamide (22%), polypropylene (13%) and smaller percentages of polystyrene, polyethylene terephthalate, polyester, polyurethane and rubber (Rummel *et al.*, 2016).
- The stomach contents of 141 fish from 27 species caught in the North Pacific Subtropical Gyre were examined – microplastics were found in 9.2%. The caught fish predominantly consume zooplankton, and the authors suggested that it was possible that microplastics could enter the food web within prey (Davison & Asch, 2011).
- A field study of Norway lobster (*Nephrops norvegicus*) found that 83% in a sample collected by trawling the Clyde Sea had plastic filaments in their stomachs. Researchers concluded that plastic could accumulate in lobster, either by accidental ingestion or if the lobster eats plastic-contaminated prey (Murray & Cowie 2011).
- In the North Atlantic 11% of 761 field-sampled mesopelagic fish had ingested small plastic debris (Lusher *et al.*, 2016).
- Microplastics have been detected in brown mussels from the Santos Estuary in São Paulo, Brazil (Santana *et al.*, 2016) and common mussels (*Mytilus edulis*) from the mainland China coastline (Li *et al.*, 2016b).
- Microplastics were found in the common mussel (*Mytilus edulis*) in the North Sea and the Pacific oyster (*Crassostrea gigas*) in the Atlantic Ocean. Both species had been grown for human consumption (Van Cauwenberghe & Janssen, 2014).

Route of uptake of microplastics



Marine species ingest microplastics in different ways: mussels and oysters filter-feed; crabs inspire across the gills and ingest through the mouth; fish ingest through the mouth.

Ingestion of microplastics may be a largely non-selective process by filter feeders. For more selective feeding organisms such as fish, intake of microplastics may occur through a combination of ingestion of contaminated prey or direct accidental ingestion of microplastics if mistaken for prey. It is also possible that, in some species, microplastics could be actively selected for ingestion (Rummel *et al.*, 2016; Lusher *et al.*, 2016). One study

published this year has suggested that newly hatched European perch larvae may prefer microplastics to its usual diet of zooplankton, when microplastics are present in abundance (Lönnerstedt & Eklöv, 2016).

Accumulation in species and transfer in the food chain

One concern is that microplastics could transfer or accumulate in the food chain as predators ingest contaminated prey.

For example, Mazurais *et al.*, (2015) suggest that if European sea bass larvae (*Dicentrarchus labrax*) were consumed by organisms higher up the food chain, microplastics could build up in a predator. There are two key issues: the physical accumulation of microplastics in the food chain, and their potential contribution to the accumulation of chemical contaminants. Studies looking at the transfer of microplastics within the food chain include the following:

Fish

- In a lab experiment, microplastics were found to have translocated from the gastrointestinal tract in mullet (*Mugil cephalus*) to its liver tissue (Avio *et al.*, 2015).
- A feeding experiment using streaked shearwater chicks fed the birds with polyethylene resin pellets collected from Kasai seaside park in Tokyo Bay. The birds were also fed wild fish. Polychlorinated biphenyls (PCBs) were detected in the fish fed to the chicks, because the fish ingest PCBs through their prey (such as copepods). The study found that polychlorinated biphenyls could transfer from contaminated plastics to the birds. Seabirds could be exposed to such contaminants

by eating contaminated prey (fish). But research on the impact of these chemicals is needed (Teuten *et al.*, 2009).

- A laboratory experiment investigated transfer of microplastics through three steps in a food chain (three trophic levels) and looked at the effect of microplastics on the top fish predator. When compared to control fish, the microplastics-fed fish spent a longer time feeding, were less active, spent more time together in a shoal and expended less time and energy exploring the tank (Mattsson *et al.*, 2015).

Bivalves

- Blue mussels (*Mytilus edulis*) contaminated with microplastics were fed to common crab (*Carcinus maenas*). Some microplastics were seen in the crabs 21 days following ingestion of the contaminated mussels, which, say the authors, suggests that microplastics could transfer in the food web from prey to predator. In turn, this suggests that common crab (*C. maenas*) could transfer microplastics to a predator (Farrell & Nelson, 2013).
- Common mussels (*Mytilus edulis*) are filter feeders and have been shown to retain tiny microplastics of 3 µm or 9.6 µm. The microplastics accumulated in the gut, translocated to the circulatory system within three days and remained in the mussel

for more than 48 days. Short-term exposure did not result in any adverse biological effects (Browne *et al.*, 2008).

Lobster

- In laboratory feeding experiments, Norway lobster (*Nephrops norvegicus*) caught in the Clyde Sea were kept in tanks and fed plastic-seeded fish. Twenty-four hours later every one of the lobsters had plastics in their stomachs, and the authors note that there is the potential that over time plastic could accumulate (Murray & Cowie, 2011).

Zooplankton

- In a lab experiment, mysid shrimp were fed microplastics-contaminated zooplankton. The shrimp were shown to have ingested the microplastics, suggesting the possibility of transfer through the food web by predators that ingest plastic-contaminated prey (Setälä *et al.*, 2014).

Physical and chemical effects of microplastics consumption

Published laboratory studies have shown that microplastics can have chemical and/or physical effects on marine organisms.

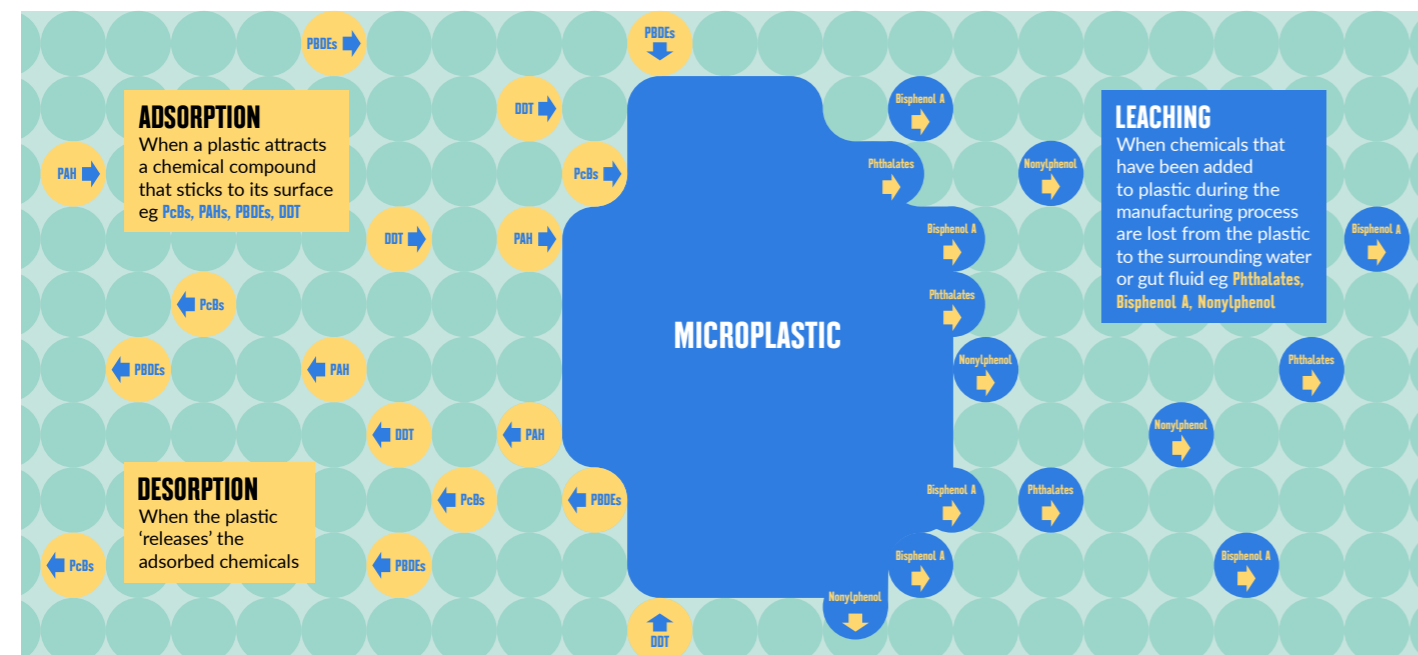
A laboratory experiment in which European sea bass (*Dicentrarchus labrax*) was fed polluted plastic (PVC) pellets found that, after 90 days, 50% of fish fed uncontaminated pellets and 50% of fish fed polluted pellets had severe alterations to the intestinal tract. The other 50% of the sample had pronounced alterations to the intestinal tract (Pedà *et al.*, 2016).

The impact of ingesting microplastics on marine organisms could depend on the species or the developmental stage

of the organism; eggs, larvae and young marine organisms are more vulnerable than adults. Authors of a study on young fish concluded that microplastics chemically and physically impact the hatching and development of European perch eggs and larvae by affecting their activity, feeding and responses to threat from predators (Lönnerstedt & Eklöv, 2016).

When the common shore crab (*Carcinus maenas*) and the copepod *Calanus helgolandicus* ingested microplastics, their feeding slowed, they had less energy and exhibited reduced egg hatching. *C. helgolandicus* is a key species in the marine food web and is eaten by fish and invertebrates (Cole *et al.*, 2015).

Microplastics and plastic-associated toxic contaminants can also impact the food chain if ingested by lower trophic organisms. The lugworm (*Arenicola marina*) plays an important part in turning over the ocean's sediment. In an experiment (Wright *et al.*, 2013), lugworms had an inflammatory response to long-term exposure to unplasticised polyvinyl chloride (UPVC), which resulted in reduced feeding and halved energy levels. The effect was that the lugworms' growth and reproduction were reduced, as was the turnover of sediment, with a potential effect on the ocean's ecosystem.



Toxicology: adsorbing, desorbing and leaching of contaminants to and from microplastics

Microplastics in the marine environment are a serious concern because they may release (or leach) toxic chemicals into the surrounding water, and also attract (or adsorb) chemicals onto their surface, which can have toxic impacts on living organisms.

Leaching: Scientific studies have recognised the toxicological effects of plastic additives (chemicals intentionally added to the original plastic items), which can leach from microplastics, such as bisphenol A (BPA), a known endocrine-disrupting compound (Michałowicz, 2014; Perez-Lobato, *et al.*, 2016). Nonylphenols affect the endocrine system (Soares *et al.*, 2008) and PBDEs also have biologically toxic effects (Darnerud, 2003). (See table 1).

Adsorbing: Once plastics are in microscopic form, whether as fragments of larger pieces or as deliberately manufactured microbeads, some of them can attract, or adsorb, persistent, bioaccumulative and toxic pollutants from seawater such as persistent organic pollutants (POPs).

POPs are toxic synthetic chemicals such as pesticides or industrial products that can bioaccumulate in

tissue and resist degradation. Their existence in the natural environment is well documented, as are their health impacts on both humans and wildlife (see table 1).

Studies indicate that polymers such as polyethylene, polypropylene, nylon and plasticised polyvinyl chloride are among the most likely to accumulate POPs (UNEP/GPA 2006; Stockholm Convention) and unplasticised polymers such as polyvinyl chloride and polystyrene are less likely to accumulate high levels of POPs (Syberg, *et al.*, 2015). Indeed one study reported that polypropylene concentrated certain toxic compounds to levels up to a million times greater than in the surrounding seawater (Mato *et al.*, 2001).

Whilst the extent to which such contaminants are transferred from ingested plastics into living tissues is as yet unknown, plastic particles may therefore be acting as one contributing source of hazardous chemical exposure in marine species and, therefore, humans, even if models suggest that, for some of those chemicals, intake via contaminated prey may currently remain the predominant route of exposure (Koelmans *et al.*, 2016).

Laboratory studies cannot entirely recreate the exposures to chemicals experienced by marine species under

natural environmental conditions. Nevertheless, much of current understanding of the interaction between microplastics, chemical contaminants and organisms has necessarily come from such studies. For example, rainbow fish (*Melanotaenia fluviatilis*) exposed under controlled conditions for 21 days to microplastics contaminated with the brominated flame retardant chemicals PBDEs contained significantly higher levels of these chemicals than the control group; longer exposures (63 days) resulted in even higher levels in fish (Wardrop *et al.*, 2016). In another recent study, European sea bass (*Dicentrarchus labrax*) were exposed to microplastics that had been immersed in Milazzo harbour in Italy for three months in order to mimic natural adsorption of contaminants from the seawater. Results showed severe impacts on the intestines not only of fish that had fed on contaminated microplastics, but also those that had fed on 'clean', unexposed microplastics, suggesting that even uncontaminated microplastics can have a negative effect on fish health (Pedà *et al.*, 2016).

Clearly the behaviour of microplastics as they degrade with age and weathering, and their affinity for contaminants is not fully understood (Teuten *et al.*, 2009).

Further research will be required to understand, for example:

- The extent to which contaminants are leached from microplastics into the surrounding water.
- The extent to which contaminants in the marine environment are adsorbed to plastics.
- The effects of complex mixtures of plastic-associated contaminants with seawater (Li *et al.*, 2016; Engler, 2012).
- Which chemicals sorb to which types of plastic.
- The effects of plastic-associated chemicals on endocrine function, which regulates growth, metabolism and reproductive activity (Rochman *et al.*, 2014b).

	Chemical	Function	Potential effects
Monomer	Bisphenol-A (BPA)	Monomer in production of polycarbonate plastics and epoxy resins	Possible endocrine disruptor. Concerns for toxicity to development, especially in unborn children and infants
	Phthalate esters (phthalates), such as DEHP, DBP & DEP	Plasticisers/softeners to make plastics more flexible, especially in PVC Solvent and fragrance fixers in perfumes and cosmetics	Some phthalates are toxic to reproduction. Others can cause damage to the liver at high doses
	Nonylphenol (NP)	Antioxidant, plasticiser and stabiliser in plastics. Also formed from the partial degradation of nonylphenol ethoxylate industrial detergents	Extremely toxic to aquatic life. Endocrine disruptor in fish, capable of causing feminization. Concerns over reproductive and developmental toxicity in other animals and in humans
Additives	Polybrominated diphenyl ethers (PBDEs)	Fire retardant used in some plastics, foams and textiles. May be present in plastics as additives or adsorbed to surfaces as contaminants from the surrounding environment	Potential endocrine disruptor, especially to thyroid function. Concerns for effects on neurological development, behaviour, the immune system and the liver
	Polychlorinated biphenyls (PCBs)	Formerly used as flame retardants and plasticisers in some plastics, and as insulating fluids in transformers	Toxic to the immune system, reproduction and the developing nervous system in wide range of animals. Can cause liver damage and some cancers
	Polycyclic aromatic hydrocarbons (PAHs)	Products of incomplete combustion of fossil fuels, as well as occurring as ingredients in oils and coal tars	All are persistent and bioaccumulative. Some are carcinogenic, mutagenic and toxic to reproduction
Contaminants	Pesticide residues, such as DDT and HCHs	Used in the past as insecticides for agricultural and urban use. DDT now restricted for malaria vector control	DDT highly toxic to aquatic life and a potential endocrine disruptor and reproductive toxicant. HCHs toxic to liver and kidney. Some suspected endocrine disruptors and possible human carcinogens

Table 1: Examples of common monomers, additives and environmental contaminants found to be associated with microplastics

3. Impact of microplastics on human health: human consumption of plastic contaminated seafood

Research into the toxicological consequences of microplastics being transferred by contaminated marine organisms to humans is still in its infancy and requires further investigation (Law & Thompson, 2014).

However, given the widespread occurrence of microplastics in marine species consumed by humans (particularly species in which the entire soft flesh is consumed, such as shellfish) it is inevitable that humans eating such foods will ingest at least some microplastics. Though there have been attempts to estimate the human intake, actual exposure will fall within wide margins and may remain very difficult to quantify in practice.

Galloway & Lewis (2016) identify a number of possible human health concerns relating to ingestion of microplastics from seafood, including direct interactions between microplastics and our cells and tissues and their potential to act as significant additional sources of exposure to toxic chemicals as a result of their high surface areas and propensity to adsorb and leach contaminants and additives. Major gaps in scientific knowledge and understanding remain, however, making it very difficult to assess the level of risk to human health.

In drawing the conclusion in its recent report that microplastics in seafood do not currently represent a human health risk, a major review by UNEP (2016) nonetheless also highlights the limitations to data and the uncertainties that remain, stressing in particular that there is insufficient evidence to assess the potential for transfer of contaminants to the fish flesh, and hence be made available to predators, including humans. UNEP's

review goes on to conclude that our understanding of the fate and toxicity of microplastics in humans constitutes a major knowledge gap, as well as noting the potential for microplastics to act as surfaces for the transport and dispersal of pathogens relevant to human diseases.

Many of the chemical additives and contaminants found to be associated with microplastics, or that are known to accumulate readily on the surface of microplastics, are certainly of significance to human health, as well as to that of wildlife. The table opposite lists some of those chemicals, along with the toxicological hazards known to be associated with exposure to them, whatever the route.

Medical research literature is a useful guide in determining any potential consequences of humans ingesting microplastics, especially those at the smallest (nano) scale. It is already clear from the medical literature that nanoparticles smaller than 100 nm can be absorbed through endocytosis into any cell, but nanoparticles larger than 100 nm are taken in by phagocytosis (by a macrophage). Other considerations pertinent to the potential toxicity of plastic particles to humans include the size and shape (spherical, rod, triangular) of plastic debris, and the consequences should many particles accumulate (Ojer *et al.*, 2015).

4. Conclusions

Microplastics are ubiquitous in the marine environment. We know from a number of studies analysing field samples and from laboratory experiments that microplastics can be taken in by a number of different marine organisms and can be transferred in the food chain. Research scientists are now working to identify the physical and toxicological effects that microplastics may have on marine – and other – organisms.

However, it is important to remember that the field of microplastics research is in its infancy. Uncertainties and knowledge gaps make it difficult to be conclusive about the impact that microplastics may have on seafood, on the marine environment or on human health. Until we have definite answers as to the impact that microplastics may have, it is prudent to apply the precautionary principle.



Petri dish containing a sample of marine debris and zooplankton
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5. Recommendations for future research

1. The physical effects of microplastics on the gut and tissue of marine fish and shellfish needs to be determined. Methods for detecting and analysing microplastics would need careful consideration prior to experimentation, in part to allow comparison with other studies.
 2. We need to understand the extent of bioaccumulation of toxic contaminants from plastics in fish and shellfish tissue, particularly in organisms that are consumed by humans.
 3. Is there a correlation between the age of fish or shellfish and the accumulation of plastic within a given species?
 4. What is the extent of bioaccumulation of persistent organic pesticides (POPs) and other toxic chemicals in organisms that have ingested microplastics, and the potential for POPs to transfer on a trophic level?
 5. What is the sublethal effect on fish or shellfish of a chosen common plastic-associated toxin, or the sublethal quantity of microplastics ingestion?
 6. Protocols to identify accurately microplastics and associated chemicals in fish gut, fish tissue and shellfish and in the marine environment should be standardised. Standardisation will help to estimate levels of pollution and exposure, and to formulate risk assessments.
 7. There is a need for field data to assess the quantity of microplastics in the ocean, including sources, movement in the currents and sink rate. We also need to determine the rate at which different plastics break down and the patterns of distribution of plastics of different sizes after they've entered the marine environment.
 8. To what extent do microplastics cross membranes and cell walls in fish, shellfish and other organisms, including humans? And do microplastics increase the stress burden on fish, shellfish or other organisms?
 9. Do marine organisms actively or accidentally ingest microplastics?
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