Update on the sources, fate, effects and consequences for the Seafood Industry of microplastics in the marine environment

Summary

'Microplastics' is the term that refers to a wide range of particles made from manmade polymers with an upper size limit of 5 mm. They can enter the marine environment either as primary particles such as microbeads or micro fibres or as secondary particles formed from the breakdown of marine litter by the action of ultra violet light and mechanical agitation. There are uncertainties surrounding the quantity of microplastics in the marine environment and their rate of increase. However, even if environmental inputs of plastics were to cease, the weathering of larger particles already present in the marine environment will continue to produce microplastic particles for many years.

The most important issues for seafood consumption are the consequence for fish and human health from the ingestion of microplastics, and the potential pollutant loads attached to the microplastic particles' surfaces. The fate of microplastics within marine ecosystems and their potential effects on ecosystems and human health are beginning to be understood, however there are still major gaps in our knowledge, particularly in relation to smaller (<150 micrometre[1]) particles. The wide variety of microplastic particles and the differing ways in which they are fragmented means this is a challenging field of study. Public awareness of this issue is also on the rise in response to increased media coverage and the iconic *Blue Planet 2* television series.

This short report is an update of a previous Seafish Information Sheet produced in 2016. This latest version includes key findings from recent research studies on the implications of plastics on the marine environment, which include:

- The extent of microplastics contamination in land and freshwater systems as a key source of contamination of the marine environment through fresh-water run-off.
- Microplastic particles in seafood are considered to be a small source of human exposure to these substances compared with other dietary sources.
- An improved understanding of the physiological pathways of microplastics; some particles smaller than 150 micrometres have been observed to cross the digestive tract wall in mammals, but how the body deals with these particles is still unknown. The ability of nanoplastic particles to access organs has been highlighted but there is still uncertainty about the physiological impacts.
- Risk that laboratory contamination could result in higher levels of microplastics being recorded in fish.
- Time series data on plastic levels in the North Sea has been analysed and found to be stable since 2000 but at a level well above the agreed environmental quality objective.

As before this paper also identifies some of the key information gaps surrounding this issue. As new research becomes available further information updates will be provided.

[1] 1 micrometre = 1 µm = 10^{-6} m; see table on page 2 for definitions

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Introduction

The sources, fate and effects of microplastic particles on marine ecosystems have been reviewed comprehensively by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) an interagency body of the United Nations and by the Food and Agricultural Organisation (FAO) amongst others. This short report is an update of a previous Seafish Information Sheet produced in 2016. This latest version includes key findings from three recent research studies (GESAMP, (2015), GESAMP, (2016), FAO Technical Paper No 615 (Lusher et al, 2017)) and other sources, on the implications of plastics on the marine environment. It discusses the potential consequences for the seafood industry together with a brief gap analysis and recommendations for future work.

Definition of microplastics

Microplastic particles are defined in the context of this paper as plastic polymer particles smaller than 5 mm. This includes particles measured in micrometres (µm; 10^{-6} m) and nanometres (nm; 10^{-9} m). Nanoplastic particles are defined in Lusher (2017) as 1 to 100 nm (10^{-9} to 10^{-7} m) in size. An overview of particle sizes and units is presented below:

Classification	Size range of particles (longest dimension)	Units of measurement in relation to metres		
		Symbol	Standard form	Decimal
Micro	Less than 5 mm	mm	10^{-3} m	0.001m
		µm	10^{-6} m	0.000,001m
Nano	Between 10^{-7} m and 10^{-9} m	nm	10^{-9} m	0.000,000,001m

Shapes of microplastic particles range from fibres to spheres with varying levels of surface roughness and sizes include fine particles (~200 nm) down to ultra-fine particles (<200 nm).

Sources of marine microplastics

Microplastic particles are derived from fossil hydrocarbons and polymers produced during industrial processes. Although the issue, in the context of this paper, is defined as a marine issue, microplastics in the marine environment originate predominantly from land based activities.

Primary microplastic particles enter the marine environment as particulates and include microfibre particles derived from textiles, micro beads used in cosmetics, and much finer particulates used in industrial abrasives and powders used in moulding.

Secondary particles are derived from degraded plastics; sources include vehicle tyre dust, fibres from clothes in domestic effluent and particles derived from weathering of larger items of plastic items in the marine environment. The level of microplastic contamination in land and freshwater systems is also recognised as an important source of contamination of the marine environment through freshwater run-off (Rochman, 2018).

Although microplastic particles greatly outnumber large (macro) plastic items in the marine environment, they still make up only a small proportion of the total mass of plastics in the ocean. This is relevant because regardless of attempts to manage plastic litter, the weathering of larger particles already present in the marine environment will continue to produce microplastic particles for many years.

Issue of microplastics

Although there are natural polymers in the ocean such as cellulose and lignin from plant material and chitin from crustaceans, together with starch, protein, DNA and others, these readily degrade in marine ecosystems. However, manmade polymers are persistent, widespread and ubiquitous in the marine environment. They have been found in deep-sea habitats in the Northwest Pacific, down to depths of 5,755 m. There is evidence that plastic litter, predominantly sourced from land-based processes, becomes concentrated in areas of slow circulation in the middle of the 'oceanic gyres' which dominate the hemispheric circulations of the world's oceans.

Fragmentation (the breakup of large plastics to microplastic particles) is mediated by ultra violet (UV) light and mechanical agitation as would be experienced at the ocean surface and along the sea shore. Knowledge of the fragmentation rates and mechanisms is needed to reliably infer the rates of microplastic particle generation, their particle size distribution and their impact on different living organisms. This crucial information, especially fragmentation mechanics, is not known even for common plastic materials. Adding to the challenge is the constant innovation in material science, which is producing 'new' polymers whose characteristics and their likely impact on the environment are often unknown.

Effects of microplastics

The size range and composition of microplastic and nanoplastic particles means that the extent of their effects is potentially wide. Their effects need to be understood at the ecological and physiological levels; both the direct effects of the particles and the indirect effects of other constituents associated with them. Assessing the implications of microplastics on marine organisms and on humans requires an understanding of how:

- plastic particles are taken up by the body;
- body processes respond to them;
- toxic substances and microbes, which may be associated with the plastics, behave and the implications of these effects.

There is evidence that microplastics have an effect on individual organisms. The GESAMP (2016) report discusses interactions with physical and biological matrices, including a diverse range of organisms in the marine environment ranging from phytoplankton through to fish and seabirds. However, it has proved difficult to measure ecological impact such as changes in biodiversity or alteration of marine food webs. This is largely because researchers have not been able to design experiments that truly measure ecological impacts from microplastic debris (GESAMP, 2016).

At a general level, it is understood that microplastics have the potential to affect the productivity and biodiversity of marine ecosystems, but quantifying to what extent has proved difficult.

Direct effects

Microplastic particles are known to be ingested by species at all levels in the marine food chain, from plankton to macro fauna, and reported in the stomachs of fish and birds. However, Hermsen et al, (2017), found a low incidence of ingestion of microplastic particles in North Sea fish; of the 400 fish examined, only one fish, a sprat contained microplastics. This study emphasises the potential risk of contamination in the laboratory and pointed out that studies which did not appropriately manage this risk reported much higher levels of microplastics in fish. This suggests that actual levels of microplastics in marine organisms could be lower than initially thought. Microplastics also interact with bacterial and algal communities, through the formation of films of micro-organisms on the particles. Uptake via the gills of very fine particles (8-10 µm) has been shown to occur in shore crab.

Evidence relating to the migration of microplastics into tissues or body fluid has been obtained from laboratory studies of filter-feeding mussels and sediment deposit-feeding lugworms. However, there are few studies confirming the presence of microplastics in tissues outside the digestive tracts of organisms collected from the marine environment. Both lugworms and mussels were shown to be able to take particles into their tissues under experimental conditions but it is uncertain whether the particles are excreted or transferred to other organs. There is evidence that mussels can accumulate particles in connective tissue but this was observed at very high concentrations of particles which may not be replicated in the natural environment.

There is also limited information available on the presence of microplastic particles outside the digestive tract in commercial fish species. Collard et al, (2017) (using clean techniques similar to Hermsen et al (2017)) found microplastic particles in the livers of European anchovies. These particles were of a larger size (124-438 µm) than those found in organs and tissues outside the digestive tract in mammals. However, it is uncertain whether the particles passed through the gut at this larger size, or if smaller sized particles agglomerated inside the fish's liver. The need for further information on the level of microplastics in fin fish flesh has been identified by GESAMP (2016) as an important requirement.

Laboratory investigations of sub-lethal effects of microplastics have shown that the health, feeding, growth and survival of organisms from lower trophic levels are affected. However, most of these effects have been demonstrated at higher concentrations of particles than are normally found in nature. There is little direct evidence of these effects in the field (GESAMP, 2016).

Lusher et al, (2017) provides an assessment of microplastic particles in mammals, including humans, dogs and rodents. The result is a composite overview of how the mammalian system treats micro and nano plastic particles, although there is variation between species. Key points from the study include:

- In general, after oral ingestion the largest fraction of the ingested micro and nanoplastics will be excreted via faeces. There is more uncertainty regarding the effect of smaller particles (less than 150 µm) which have the potential to pass through the gut wall. Absorption rates of this size range have been found to be small, between 0.04% and 0.3% of the administered dose.
- Particles of less than 150 µm have been found in the lymph, a bodily fluid containing components of the immune system, and linked with the blood. Particles of 110 µm in size have been found in the hepatic portal vein, which links the digestive tract to the liver. This would suggest that the particles have passed through the wall of the digestive tract.
- Not much is known about the distribution of particles after their absorption, but it is known that particles in the lymph, larger than 0.2 µm can pass back into the gut via a filtration system in the spleen. The liver is also capable of returning micro-particles to the digestive system via the bile.
- Particles of less than 20 µm are likely able to access organs. Nanoplastic particles can cross the placental barrier as shown by experimental studies using ex-vivo human placentae.
- Up to 7% of ingested nanoplastic particles are reported as absorbed into the mammal's body via the digestive system. However, there are likely to be other sources, for example airborne particles which could enter the body via the lungs. There are potential effects of these particles on the immune system and the digestive system in mammals but the presence of these effects in humans is unknown.

Due to variations between species and particle types there are inevitably uncertainties concerning the effects of these particles. However, Lusher's central findings are that (1) only particles of less than 150 µm can cross the mammalian digestive tract wall, causing exposure to internal organs, and (2) nano particles can penetrate further into the body's systems.

The challenge of emulating the natural environment in experiments means the 'actual' direct effects of microplastics remains uncertain.

Indirect effects

Microplastic particle surfaces are potentially active sites for adsorption of pollutants; the smaller the particle size the greater the surface area, per unit weight of particle, is available for these interactions. The nature of the surface of the particle is also important with many characterised as being hydrophobic or water repelling, making them attractive to persistent organic pollutants. There are also likely to be additives, monomers and other by-products associated with the plastic particles.

The affinity of persistent organic pollutants, which include polychlorinated biphenyls (PCBs), to the surface of microplastic particulates, has led to investigations into their potential role in mediating transfer of these pollutants to marine organisms that ingest them.

Whilst the transfer of pollutants mediated by microplastic particles has been demonstrated in experimental studies of lugworms, amphipods, fish and seabirds, the indications are that they are relatively small compared with the natural route via feeding. The extent of transfer is underpinned by theoretical considerations; contaminants transfer from particles to organisms or vice versa depending on the extent to which the particles or organisms are at equilibrium with the contaminant (GESAMP, 2016).

This was further examined by Koelmans et al, (2016) who found that at equilibrium, which is the expected condition, the fraction of pollutants attached to plastic particles was small compared with other media in the ocean. Pollutants ingested from natural prey would overwhelm that from microplastic ingestion. However a non-equilibrium condition, which is more likely the case for substances such as releasing agents and additives, can lead to substances leaching off the surface of the plastic, increasing the potential for uptake by marine organisms.

There is sufficient existing information available to estimate the transfer of contaminants from microplastics to living organisms under different scenarios and hence begin to think about a risk assessment (GESAMP, 2016). Human ingestion of contaminants and additives on microplastic surfaces from seafood is potentially of concern. The GESAMP (2015) report highlights bivalve molluscs and potentially deposit feeders (such as sea cucumbers) as a possible source. Lusher et al, (2017) also identifies small pelagic species (such as sardines) which are eaten whole.

A human exposure assessment by Lusher et al, (2017), based on the consumption of a 225 g portion of mussels, indicated that around 900 plastic particles (representing 7 µg of plastic per meal) would be ingested. Data on the highest reported levels of contaminants and additives on plastic particles were used. Using this information, an assessment of the levels of transfer of persistent organic contaminants and additives was made. Estimates show that the percentage intake of these contaminants was low, with only one contaminant making up 0.1% and the other six making up between 0.0000002% and 0.03% of total dietary intake.

There is ongoing work on plastic particles as a source of metals and the GESAMP (2016) and Lusher et al (2017) reports provide a useful conceptual framework around which these further risks can be assessed.

The issue of microbial pathogens has also been considered by GESAMP (2016). Microplastics have been shown to host microbial communities, including potential pathogens, distinct from the surrounding water and sediment. This aspect has not been widely studied.

Environmental trends

There is clear evidence of large scale increases in plastic production, with a 400% increase in global plastic production estimated since 1985 (Van Franeker et al, 2016). However, information on long term trends detailing the impact of plastics on marine organisms is limited. The primary long-term data set relates to studies in the Northeast Atlantic under the OSPAR[2] agreement.

Monitoring programmes investigating plastic fragments in seabird stomachs (Northern fulmar; *Fulmarus glacialis*) provide an index of long term trends, and have established a level of plastic contamination as an indicator of environmental quality (OSPAR 2015). The Northern fulmar was used because (1) it only feeds at sea and (2) data on stomach contents is available since the 1980s meaning that comparisons can be made over time. An agreed environmental quality objective of less than 10% of dead fulmars having 0.1 g of plastic per stomach has been set, based on levels found in relatively unpolluted environments such as the Canadian Arctic.

Trends over the past two decades have been stable at around 60% of individual fulmars exceeding the 0.1 g level of plastic ingestion (OSPAR, 2017). While there is some evidence of decreasing trends in fulmar samples obtained from coastal waters around the Netherlands (Van Franeker et al, 2016), OSPAR considers the overall levels to be stable. This lack of increase in plastic levels in fulmars, despite rising trends in overall plastic production in recent decades, suggests that waste management measures could be mitigating marine plastic impacts.

These results are only indirectly related to micro and nanoplastics since particles of this size range are too small to be detected in the survey. However, since microplastics can be derived from larger plastic fragments through their breakdown in the marine environment, the trends identified in the study are relevant.

Consequences for the seafood industry

With such a diverse range of possible compounds, particle shapes and sizes and possible interactions it is difficult to make generalisations about potential effects. However, the following issues are likely to be of most consequence:

Ecosystem Health:

The widespread distribution of these particles in marine ecosystems may affect the physiology of constituent organisms compromising their fitness and potentially affecting ecosystem functioning (GESMAP, 2016) as well as biodiversity levels. However, it remains difficult to measure ecological effects and therefore the full impacts are not understood.

Human health:

The mobility of tiny plastic particles across the mammalian gut wall has been demonstrated which would suggest that the human ingestion of microplastics from seafood is potentially of concern. The GESAMP reports identify bivalve molluscs, and other species eaten whole, as a possible source. Li et al (2018) indicate that microplastic levels detected in supermarket bought mussels present a route for human exposure. The research further suggests that their quantification be included as a food

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[2] OSPAR is the short name for the Convention for the Protection of the Marine Environment of the North-East Atlantic derived from the predecessor organisations the Oslo and Paris Commissions (www.ospar.org)

safety measure as well as for environmental monitoring purposes. Catarino et al (2018) has found that human ingestion of microplastics via household dust falling on food was a larger source of exposure to microplastics than from mussels both for UK and continental consumers.

Lusher et al, (2017) confirm that particles of less than 150 µm are able to cross the digestive tract wall of mammals, but a full description of how the body deals with these particles is not available. The ability of nanoparticles to access organs has also been highlighted but their physiological impact is still uncertain. As a consequence nanoplastic particles are of most interest to further research on human toxicology.

The role of microplastics in the transfer of pollutants in marine ecosystems is becoming better understood although the numerous types of particle and pollutants and their potential impact remains a challenge. Public health considerations mean there are regulations which place limits on levels of pollutants in seafood offered for sale; this suggests the effects should be controllable provided that monitoring and control systems are in place.

The GESAMP report (2015) makes a number of recommendations to improve understanding of human health implications which include utilising expertise from pharmacology and mammalian toxicology to better understand the fate and consequences of microplastics and nano-sized particles in particular.

While uncertainties do remain, this paper indicates that there has been considerable progress in recent years to improve our understanding of the issue and to start to address potential concerns. However, public awareness of the problem and a perception that there is a risk (even if the evidence does not support such a perception) can influence consumer behaviour and ultimately seafood sales (GESAMP, 2015 & 2016).

Li et al (2018) reiterate that the human health consequences of consumption of microplastics in seafood are uncertain and that it is difficult to fully assess these consequences in the absence of sufficient exposure and toxicological data (EFSA CONTAM Panel, 2016). As this Seafish paper highlights, while good progress has been made to improve the knowledge base there are still gaps remaining.

Public awareness of the problem and a perception that there is a risk (even if the evidence does not support such a perception) can influence consumer behaviour and ultimately seafood sales. In some laboratory studies, measures have been found to reduce microplastics in bivalves (such as depuration) however these will come at a cost (GESAMP, 2015).

Gap analysis

Many of the research gaps identified in the 2016 paper remain; although research in recent years has started narrow the gap. From a seafood industry perspective there is a need for:

1. A risk assessment of microplastic particles (particularly microplastic particles of less than 150 µm and nano-particles) and their physiological and ecological pathways in fish and shellfish to assess whether there are risks to humans consuming seafood. Seafish is commissioning research in this area.

2. Improved understanding of the role of micro plastics in contaminant transfer; while the immediate issue relating to the transfer of organic constituents has been addressed, further analysis is required for other constituents such as metals and microbes.

3. Better information on the ecosystem effects of microplastics and the extent to which plastics undermine ecosystem productivity and biodiversity. There is awareness that micro/nanoplastic particles can affect living systems, but developing valid experimental designs to determine the overall ecological risks has proved more difficult.

4. Understanding the fragmentation rates and mechanical processes that give rise to indirect sources of microplastic and nanoplastic particles.

5. An assessment of microplastic pollution from the seafood industry's own activities. This would require (1) an assessment of the relative importance of lost fishing gear, litter from vessels or packaging materials used during the production process as sources of microplastic pollution and (2) the implementation of measures to reduce the effects of those perceived to be the highest risk.

6. Influencing human attitudes and behaviours post Blue Planet 2 to meaningfully reduce the sources of macroplastic and microplastic litter.

Further work

Recent research reports (including GESAMP 2015, GESAMP 2016, Lusher et al, 2017 and Barboza et al, 2018) are important steps in the assessment of the effects of microplastic and nanoplastic pollution. These reports also include recommendations to address marine plastics which should be referred to for more information.

OSPAR has a Regional Action plan for the period 2014-2021 (OSPAR, 2014) designed to reduce litter in the Northeast Atlantic. The objective is 'to substantially reduce marine litter in the OSPAR maritime area to levels where properties and quantities do not cause harm to the marine environment'. The associated actions include quality status indicators (see above) and the *Fishing for Litter* scheme which involves fishers collecting marine litter and developing schemes to evolve best practice in the use of plastic in fishing gear and mitigating their impact on the marine environment. This will contribute to Gap Analysis #5 above.

In Europe, the Marine Strategy Framework Directive (2008/56/EC) sets out 'Good Environmental Status' in relation to marine litter under *Descriptor 10: Properties and quantities of marine litter do not cause harm to the coastal and marine environment*. This includes a requirement for a monitoring programme for marine litter which includes an assessment of its original use and possible origin. The Directive also identifies the need for indicators relating to the biological impacts of litter and an assessment of its potential toxicity.

The Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans www.jpi-oceans.eu) is a coordinating and integrating platform, open to all EU Member States and Associated Countries, which focuses on making better and more efficient use of national research budgets. There are several research projects investigating the ecological aspects of microplastics (see www.jpi-oceans.eu/ecological-aspects-microplastics.) These projects started in January 2016 and are due to complete in 2019. Preliminary results were presented at the JPI Oceans Conference in Lisbon in October 2017 and presentations can be found at http://www.jpi-oceans.eu/powerpoint-presentations-2nd-jpi-oceans-conference. The projects are as follows:

- Project **BASEMAN:** Focused on defining the baselines and standards for microplastics analyses in European waters' including the validation and harmonisation of analytical methods aimed at improving identification and quantification of microplastics in the environment.

- Project **WEATHERMIC:** Assessing how microplastic weathering changes its transport, fate and toxicity in the marine environment. This project investigates the changes that marine plastics undergo as a result of various environmental weathering processes, like UV exposure, biofilm growth and physical stress.

- Project **EPHEMARE**: This project is investigating the ecotoxicological effects of microplastics in marine ecosystems looking at uptake, tissue distribution and final fate and effects of microplastics in benthic and pelagic ecosystems and their potential role as vectors of persistent contaminants that readily adsorb onto their surfaces.

- Project **PLASTOX**: Explores the direct and indirect ecotoxicological impacts of microplastics on marine organisms' focused on ingestion and food web transfer. The study is also looking at persistent organic contaminants (POPs), metals and plastic additive chemicals associated with microplastics, and their impacts on key European marine species and ecosystems.

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