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REVIEW ARTICLE

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Microplastics in Fish and Shellfish – A Threat to Seafood Safety?

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ABSTRACT

Plastic litter in the oceans is a major environmental problem, and small size plastics (microplastics) have been detected in many species of fish and shellfish consumed by humans. The purpose of this paper is to evaluate the knowledge on microplastics in fish and shellfish in relation to a possible threat to seafood safety. In fish and crustacean species, the presence of microplastics has in most cases been investigated and detected only in the gastrointestinal tract, which is commonly not eaten, and when present, only a very small number is usually found. Bivalves are probably the main source of microplastics when consuming seafood. Preliminary assessments have suggested that the contribution of hazardous chemicals from microplastics for top consumers of bivalves is very small compared to other sources. From the current knowledge on microplastics in seafood, there is no evidence that the safety of such highly recommended food is compromised.

KEYWORDS

Microplastics; fish; shellfish; seafood safety

Introduction

World fish and shellfish utilization have been steadily increasing during the last decades and in spite of population growth, the per capita consumption has increased from about 9 kg in 1961 to more than 20 kg today (FAO 2018). Seafood is an important part of a healthy diet, and authorities in several countries have for many years been advising people to eat more seafood (FAO/WHO 2011; Kris-Etherton et al. 2009; Rimm et al. 2018). Two weekly portions, one with lean and one with oily fish, are often recommended. However, the significant focus on microplastic pollution in the oceans may counteract this important dietary advice. Several publications have reported on the presence of small plastic debris, i.e. microplastics, in fish and shellfish consumed by humans and expressed concerns that this may affect human health negatively (Bonanno and Orlando-Bonaca 2018; Rochman et al. 2015; Santillo et al. 2017; Wang et al. 2018). Based on current knowledge, others have indicated little or no concern with regard to microplastics in fish and shellfish and seafood safety (Bouwmeester et al. 2015; Lusher et al. 2017; Rist et al. 2018; Waring et al. 2018). Although it is important in scientific journals and in the public media to highlight the problems with marine plastic pollution, it is also important that consumers are not unnecessarily discouraged from eating seafood. The objective of this paper is to evaluate the knowledge on microplastics in fish and shellfish in relation to a possible threat to seafood safety.

Marine plastic pollution

It is difficult to imagine a modern world without plastic as it is used in many areas of society, such as packaging of foods, in cars, textiles, fishing gear, and medical devices. The versatile use of plastics is

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among other things due to properties like lightness, strength, durability, and low cost. However, these same properties make synthetic materials such a large environmental problem. Plastic is highly resistant to degradation and due to poor waste management in many parts of the world, it has been accumulating in nature. This is particularly visible on beaches and in the oceans, where plastic debris may be transported with currents and wind all over the world. To indicate the magnitude of this environmental problem, it has been estimated that about 5 trillion plastic pieces of different sizes weighing about 250,000 tons are floating in the oceans (Eriksen et al. 2014). The increased awareness of plastic pollution in the marine environment in the last years has fortunately led to improved waste handling, bans on including microplastics in some cosmetics, and reduced use of disposable plastic items like shopping bags and cutlery in many countries.

Although there is no accepted size definition of microplastics, it is often categorized to be in the range of 0.1–5,000 µm. Macroplastics are debris above 5 mm, while nanoplastics are classified to be between 1 and 100 nm in size (EFSA 2016; Koelmans et al. 2015). Macroplastics in the oceans may originate from several sources such as rivers (Schmidt et al. 2017), lost or abandoned fishing gears, illegal waste dumping at sea, or mismanaged plastic waste in general (Lusher et al. 2017). Such litter may have dramatic consequences for animals, including birds, turtles, marine mammals, and fish, like entanglement in lost fishing nets or ingestion of macroplastics interfering with normal feeding resulting in suffering and premature death (Kühn et al. 2015).

Microplastics are often categorized as two types: primary and secondary. Primary microplastics are produced in size less than 5 mm and released to the environment either accidentally or by wastewater. These may be pellets used in the production of larger plastic items or, for example, microbeads included in cosmetics or used in industrial processes. Secondary microplastics originate from breakdown of larger products due to weathering of debris on shorelines and in the sea, UV-induced brittleness and subsequent fragmentation of plastics, or from washing of synthetic textiles (Andrady 2017). It has been estimated that more than 1900 microplastic pieces (mostly fibers) may be released to the wastewater when washing a garment of synthetic clothing in a household machine (Browne et al. 2011). Although the majority of these fibers are removed in wastewater treatment plants, a substantial amount is lost in the effluent water (Magni et al. 2019).

According to recent reviews, virtually nothing is known about the presence of nanoplastics in the marine environment, including seafood, since no methods are available for the detection or quantifications (EFSA 2016; Koelmans et al. 2015). Nanoplastics in the environment could be the most dangerous plastic since it has been experimentally demonstrated that nanoparticles may be absorbed by the gastrointestinal (GI) tract and end up in different organs of animals (reviewed by Lusher et al. 2017).

Microplastics in fish and shellfish

The gastrointestinal tract from a large number of fish species has been investigated for the presence of microplastics (compiled by Barboza et al. 2018). A small number of particles are often found, and generally far from all of the specimens of a species investigated contain plastic in the GI tract. Some examples are presented in the following. Rochman et al. (2015) obtained 76 whole fish (11 species) from a fish market in Indonesia and found that 28% of the fish contained plastic debris in the GI tract. They also studied 64 individual fish (12 species) purchased in California and found microplastics in 25%. In a study of 263 fish (26 commercial species) caught off the coast of Portugal, 20% had microplastics in the GI system, and of these, 67% contained one plastic particle (Neves et al. 2015). The presence of plastic debris has also been investigated in 290 GI tracts from 3 demersal species (Atlantic cod; *Gadus morhua*, common dab; *Limanda limanda*, and European flounder; *Platichthys flesus*) and 2 pelagic species (Atlantic herring; *Clupea harengus* and Atlantic mackerel; *Scomber scombrus*) in the North Sea and the Baltic Sea (Rummel et al. 2016). Plastics, of which 74% were categorized as microplastics, were detected in 5.5% of the samples. Of the 51 mackerel studied, 9 were found to contain plastic debris, while only 1 out of 81 cod had plastic in the GI tract.

Foekema et al. (2013) reported that none of 84 Atlantic mackerel and only 2% of 566 Atlantic herring caught in the North Sea contained microplastics in the gut. The authors also investigated other species from the North Sea and reported that the number of individuals with ingested plastics was low, and usually only one particle was found. Hermsen et al. (2017) examined microplastics in fish from the North Sea taking much care to avoid contamination from external sources and found it in only 1 out of 400 GI tracts. Wesch et al. (2017) and Torre et al. (2016) have demonstrated that the number of microplastic particles in biological samples easily can be overestimated unless such strict methodological precautions are taken. Other studies have found that from 2% to 36% of the investigated fish contained plastics in the guts, and when present, an average number of 2 items or less per fish was detected (Anastasopoulou et al. 2013; Bellas et al. 2016; Bråte et al. 2016; Lusher et al. 2013, 2016). It has been shown that small indigestible solids or larger microplastics do not accumulate to any large extent in the digestive system and are egested in the feces (Dos Santos and Jobling 1991; Grigoriakis et al. 2017; Jovanovic et al. 2018). This may contribute to the findings that microplastics are absent in many GI-tracts, and when present, the average number is low. Results from examining gastrointestinal systems may, however, be of limited relevance to seafood safety, since these organs are not normally consumed (EFSA 2016).

Relatively few studies have been carried out on the microplastic content in species that often are consumed whole, e.g. sardines, anchovies, and sprats. Studying European pilchard (*Sardina pilchardus)* and European anchovy (*Engraulis encrasicolus*) caught along the Spanish Mediterranean coast, Compa et al. (2018) found that 14–15% had microplastics or natural fibers in the GI tract. Beer et al. (2018) investigated the content of microplastics in the digestive system of Atlantic herring and European sprat (*Sprattus sprattus*) caught in the Baltic Sea during the last 30 years. Independent of the year of harvest, approximately 20% of the fish contained microplastics, and 1 to 2 pieces were detected in the GI tract of these individuals. In another study, only 1–2% of Atlantic herrings and sprats from the Baltic Sea were reported to contain microplastics in the guts (Budimir et al. 2018). Sprats and sardines are commonly sold as canned products, and Karami et al. (2018) recently investigated 20 different brands of such products for the presence of what they called micro- and mesoplastic (size range 0.149–10 mm). They found that plastics were absent from the fish product in 16 canned brands, while the fish in 4 brands contained 1 to 3 particles per can. It is generally accepted that microplastics of size 0.150 mm (150 µm) or above are not absorbed by the intestine (reviewed by Lusher et al. 2017), and it was, therefore, suggested that plastic pieces in the cans must come from GI tracts present or from contamination during the canning process. Small pelagic species are usually beheaded, and sardines are often gutted prior to canning, while the smaller sprats are commonly kept alive in net pens for at least 48 h after harvesting to empty the intestinal tract before processing (Warne 1988). Consuming canned sprats and sardines will clearly represent low exposure to microplastics compared to other sources like the air we breathe (Catarino et al. 2018; Rist et al. 2018); based on current knowledge on microplastics in fish, these seafood products should be regarded as safe to eat.

Some commercially important crustaceans have been studied, and in a paper by Murray and Cowie (2011), it was reported that 83% of *Nephrops norvegicus* (Norway lobster) caught on the west coast of Scotland contained plastics, mostly filaments, in the stomach. However, since only the tail muscle, not the guts, is eaten by humans, the risk of ingesting plastics was regarded as low. Devriese et al. (2015) studied microplastic (>20 µm) contamination in brown shrimp (*Crangon crangon*) harvested in the Southern part of the North Sea and English Channel. In whole shrimps, they found an average amount of 1.23 pieces per shrimp, while nothing was detected in the peeled shrimp, which is the part consumed. The conclusion was that fibers >20 µm are not transported from the GI tract to the edible muscle. However, the GI tract is not completely removed during the peeling process, and the authors estimated that depending on the amounts of shrimps eaten, between 15 and 175 microplastic particles could be ingested by consumers in Belgium per year.

Bivalves are of more concern with regard to transferring microplastics to humans since they are mostly consumed whole with the digestive system included. There have been some publications quantifying microplastics in both farmed and wild bivalves. Van Cauwenberghe and Janssen (2014) determined the amount of microplastics (>5 µm) in farmed blue mussels (*Mytilus edulis*) from Germany and in cultured oysters (*Crassostrea gigas*) from France and found that the average content was 0.36 and 0.47 particles per gram wet weight soft tissue, respectively. Based on these figures, they estimated that the top consumers of bivalves in the European Union might ingest 11,000 microplastic particles per capita yearly. In another study on *Mytilus spp*. (mostly *M. edulis)* obtained from Belgian department stores and from wild specimens collected from quaysides in Belgium and The Netherlands, the average number of microplastics (>10–20 µm) was reported to be in the range of 0.26 to 0.51 per gram edible tissue (De Witte et al. 2014). Other studies have found the same or slightly higher amounts of microplastics in wild or farmed samples of this species in Europe (Li et al. 2018; Van Cauwenberghe et al. 2015). The presence of microplastics (> 5 µm) in wild or cultured *M. edulis* obtained at 22 sites along the coast of China has also been investigated, and the total numbers varied from 0.9 to 4.6 particles per gram (Li et al. 2016). They also reported that the amount of microplastics in the mussels reflected the environmental load of debris. Other bivalves have also been analyzed, and the content in nine different commercial species obtained from a fish market in China varied from 2.1 to 10.5 microplastic items per gram (Li et al. 2015). In a study from the west coast of Canada, wild and cultured Manila clams (*Venerupis philippinarum*) were observed to contain an average amount of 0.9 and 1.7 microplastic particles per gram, respectively (Davidson and Dudas 2016). Due to methodological challenges, the number of reports on the presence of smaller microplastics (approximately <5 µm) in seafood is very few (compiled by Barboza et al. 2018). The lack of harmonized analytical methods for microplastics, nanoplastics, or its compounds makes it difficult to compare analytical results between methods and/or laboratories and to obtain definite conclusions.

Microplastics and seafood safety

Microplastics (synthetic particles or fibers) have been reported in products like table or sea salt, beer (Iñiguez et al. 2017; Kosuth et al. 2018; Liebezeit and Liebezeit 2014), honey and sugar (Liebezeit and Liebezeit 2013). Others have suggested that the presence of microplastics in honey and beer has been overestimated (Lachenmeier et al. 2015; Mühlschlegel et al. 2017). However, drinking water (WHO 2019) and seafood products (Lusher et al. 2017) seem to be the most studied sources of dietary intake of microplastics. Unfortunately, the number of publications on the presence of microplastics in the edible muscle is very limited (Abbasi et al. 2018; Akhbarizadeh et al. 2018) compared to the number of papers investigating the presence in the GI tract of fish (reviewed by Barboza et al. 2018). One explanation is probably that after ingestion, only smaller microplastics particles (<20 µm), which may be difficult to detect, can be translocated to different organs, such as edible muscle (Lusher et al. 2017).

Plastic debris in the oceans may contain many chemicals that can be harmful to the biota, and a pivotal question is how much will microplastics that are present in seafood contribute to the human exposure to these compounds. The chemicals may either be inherent to the plastic or acquired from the environment. Plastics have hydrophobic surfaces and will, therefore, adsorb compounds of similar chemical nature from the seawater. Much attention has been placed on persistent organic pollutants (POPs) such as polychlorinated biphenyls; PCBs, 2,2′-bis(*p*-chlorophenyl)1,1-trichloroethane; DDTs (or it metabolites DDD and DDE), hexachlorocyclohexans; HCHs and polycyclic aromatic hydrocarbons; PAHs (reviewed by e.g. Rochman 2015; Teuten et al. 2009). Mato et al. (2001) determined the concentrations of PCBs and DDE on plastic resin pellets collected at the coast of Japan and found the levels to be 10^5–10^6 times higher than in the surrounding seawater. POPs have also been detected in plastics sampled in the sea and on beaches in other parts of the world (Rochman 2015). These lipid soluble chemicals are of well-known concern in human nutrition, and the levels in food are closely monitored with threshold values in place for most of them.

There are two categories of leachable inherent chemicals in plastics of concern to human health. One is unreacted monomers in the plastics and the other is so-called functional additives included during production to improve the properties of the plastic products (reviewed by Hahladakis et al. 2018; Hauser and Calafat 2005; Hermabessiere et al. 2017). Bisphenol A (BPA) is probably the most focused on monomer and is mainly used in the synthesis of polycarbonate plastic containers and epoxy resins that, for example, line aluminum cans used for food and beverages (Hermabessiere et al. 2017). BPA is also used as a plasticizer (additive) in other types of plastics. The compound has estradiol-like activity and is therefore regarded as an endocrine disrupting chemical. It may also have other negative health effects like promoting adverse behavior and obesity (Talsness et al. 2009). Like BPA, two important and much studied groups of additives, phthalates and brominated flame retardants, are also endocrine disrupting chemicals (Talsness et al. 2009). Phthalates are mainly used in polyvinyl chloride as plasticizers to introduce flexibility and elasticity, and they can constitute as much as 70% of plastic products (Hahladakis et al. 2018). They may be found in a range of items from personal care products and food packaging plastics to medical devices like flexible tubes and blood storage bags. The potential human health effects are mainly related to interference with normal reproductive development and function (Hauser and Calafat 2005). Flame retardants are used to delay the development of a fire and are included in a large number of everyday products containing plastic such as electronic equipment, computers, furniture, and building materials. The main flame retardants used in plastic products are polybrominated diphenyl ethers (PBDEs) and tetrabromobisphenol A (TBBPA). The latter may be degraded to BPA after being released to the environment (Talsness et al. 2009).

There has been much debate regarding microplastics as a possible vector for transporting chemicals or being harmful in other ways to aquatic organisms. Several experimental studies have been carried out on the effects of microplastics on aquatic organisms, in particular bivalves and zooplanktons, and negative effects have been observed. However, as pointed out by Lenz et al. (2016), the concentrations of microplastics used in these investigations have in most cases been orders of magnitude higher than found in the oceans. These authors recommended that realistic environmental concentrations of microplastics be used in studies related to any negative effects on aquatic organisms. Rochman et al. (2013) investigated the effects of low-density polyethylene (LDPE) microplastics (<0.5 mm) contaminated with marine environmental levels of POPs fed to Japanese medaka (*Oryzias latipes*) for 2 months. They reported that PAHs, PCBs, and PBDEs increased substantially in all groups of fish (control feed, virgin plastic feed, and marine contaminated plastic feed), and at the end of feeding period, only the concentration of PBDEs was significantly higher in the fish fed the contaminated microplastic. In both groups of fish ingesting microplastics, liver toxicity was observed. However, as much as 10% of the feed was microplastics.

Seabirds commonly ingest (micro) plastics, and in an early publication, it was reported that the amount of PCBs in great shearwaters (*Puffinus gravis*) in the South Atlantic Ocean correlated with the amount of plastic in the stomach (Ryan et al. 1988). In a more recent study on northern fulmar (*Fulmarus glacialis*) from the northeast Atlantic Ocean no such correlation was found (Herzke et al. 2016). The authors concluded that ingested microplastics had minimal effects on the concentration of POPs in the birds. Several authors have reported that the current concentrations of microplastics in the oceans contribute negligible or minor amounts to the content of contaminants in aquatic organisms; the major sources are preys and seawater (Bakir et al. 2016; Beckingham and Ghosh 2017; Gouin et al. 2011; Koelmans et al. 2016; Lusher et al. 2017).

Some preliminary calculations have been made on how microplastics in the most contaminated seafood, i.e. bivalves, will contribute to the human exposure of POPs and other contaminants. The general conclusions are that the effects are very low (EFSA 2016; Lusher et al. 2017). Van Cauwenberghe et al. (2015) investigated the presence of microplastics in *M. edulis* sampled along the French, Belgian, and Dutch coastline and found an average concentration of 0.2 particles per gram tissue. Using this amount and available data from the literature on the concentrations of PCBs adsorbed to plastic particles collected from the environment and tolerable daily intake (TDI) of

PCBs, they calculated that a meal of mussels (300 g of meat) would contribute only 0.06% of the TDI of PCBs. In the study of Li et al. (2015) on commercial bivalves obtained at a Chinese market, an average number of 4 particles per gram of meat was detected. Using the same assumptions and figures as Van Cauwenberghe et al. (2015), a large meal of bivalves would still make only a small contribution to the TDI of PCBs. Similar preliminary calculations have been made for the contribution of BPA in the human diet from microplastics in consumed bivalves. The estimation was that this was small or negligible, as also expected for other additives (EFSA 2016; Rist et al. 2018).

Microplastics in oceans have been shown to harbor microbial communities different or similar to the microorganisms in the surrounding water, and even possible pathogenic species have been detected (EFSA 2016; Kirstein et al. 2016). However, the relevance for seafood safety is not known (Lusher et al. 2017). The small amounts of microplastics present and the fact that seafood, including bivalves, are most often heat-treated prior to consumption must be included in such considerations. Microplastics are also known to adsorb metals, including cadmium and lead, but the contribution from microplastics in seafood to human exposure to toxic metals has to our knowledge so far not been assessed (EFSA 2016).

Conclusions

From today's knowledge on microplastics in edible marine organisms, it is obvious that mainly bivalves, which most often are eaten whole, could contribute to the amount of ingested microplastics when humans are eating seafood. In species of fish and crustaceans, the presence of microplastics have in most cases been investigated or detected only in the non-edible gastrointestinal tract, and when present, a small number is usually found. Small pelagic fish species that commonly are consumed whole also appear to give a limited contribution. The main worries with microplastics are that they contain potentially hazardous chemicals like plastic monomers and additives or adsorb toxic pollutants from the marine environment. Preliminary assessments suggest that the contributions of these chemicals from microplastics in bivalves among top consumers in Europe are very small compared to other sources. Based on the current knowledge on microplastics present in seafood, there is no evidence that the safety of such highly recommended food is compromised. Although the total exposure to microplastics, in particular smaller size microplastics and nanoplastics, may pose significant worries, the necessary quality controlled data to perform a full safety risk assessment is lacking.

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