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Haumaru Kai Aotearoa

Risk Profile: Microplastics in the diet

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Scientific Interpretative Summary

This SIS is prepared by New Zealand Food Safety (NZFS) risk assessors to provide context to the following report for MPI risk managers and external readers.

FW18032 Risk Profile: Microplastics in the diet.

Plastics have been found in freshwater, marine and terrestrial environments. The potential effects of microplastics (fragments 1 µm - 5 mm) on human health through the food chain have been increasingly of interest internationally and in New Zealand.

To access the occurrence of microplastic contamination in foods and the impact of the availability of microplastics in food, New Zealand Food Safety (NZFS) contracted Environmental Science and Research Limited (ESR) to perform a scientific literature review. The purpose of this risk profile is to identify if experimental work is needed to determine dietary risks associated with microplastics in the environment.

Although it is thought that plastics pose a low risk to human health, the manufacturing additives or chemicals adsorbed from the environment have been associated with human health effects. It is noted that the risk to human health due to exposure to nanoparticles (fragments <1 µm) is unknown. The hydrophobic nature of plastic surfaces stimulates rapid formation of microbial biofilms, which is thought to be a potential microbial risk to humans. Plastics have also been found to facilitate the persistence and extent the movement of microbials, as well as the potential to develop unique microenvironments due to ‘hot-spots’.

The risk profile concluded that the dietary risk to microplastics cannot be determined at this moment. Further research is needed to understand the potential chemical and microbiological hazards and risks associated with microplastics for New Zealand. Research programmes are now underway in New Zealand to specifically investigate if microplastics are a food safety concern.

Science for Communities

RISK PROFILE: MICROPLASTICS IN THE DIET

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1. EXECUTIVE SUMMARY

The purpose of this report is to provide contextual and background information relevant to potential hazards of microplastic (MP) contamination through dietary exposure. Plastics are both pervasive and persistent in the environment, having been found in freshwater, marine and terrestrial environments from the poles to the equator, and from the tops of mountains to the sediments of deep-sea trenches. There is increasing evidence that microplastics are entering the food chain, however, there is very little understanding of levels within food, dietary exposure and the potential health implications. Due to the lack of knowledge about the health risks associated with MP dietary exposure this report discusses the levels of MPs and nanoplastics (NPs) in food-species and processed foods, and the potential risk factors associated with them.

MPs have been found in fin fish, molluscs, crustacea, sea cucumbers and seabirds globally. There are significantly fewer studies of the MP content of processed food, with only a single study that looked at MPs in food in New Zealand. This study only examined table salt, and the limited results do not allow determination of the potential dietary intake. The per capita yearly consumption of different mollusc species in New Zealand is around 440 g capita^{-1} yr^{-1} (Cressey, 2013). Using the average MP load detected in bivalve mollusc species the dietary exposure to MPs through bivalve consumption can be around 924 and 4620 MP fragments capita^{-1} yr^{-1}. However, the estimate for MP loads in shellfish in New Zealand is highly uncertain as there are currently no data available for the levels of MPs in shellfish grown in New Zealand waters, highlighting the need for greater assessment of the current level of contamination within food.

Plastics are generally considered to pose a low risk to human health, however the additives used in the manufacture (e.g. plasticizers) or those that become adsorbed from the surrounding environment (e.g. heavy metals) have been associated with human health effects although an understanding of the role MPs play in transferring them to humans is still in its infancy. The characteristics and levels of chemical contaminants associated with MPs in New Zealand are unknown and require study.

MPs provide a unique substrate for microbes, and consequently are thought to present a potential microbial risk to humans through either facilitating the survival and transfer of pathogens and toxic algae into food, or the promotion of virulence. The influence of MPs on microbiological health risks is a growing area of research, and currently nothing is known about the risks in New Zealand.

Knowledge of the adverse effects of the ingestion of MPs on human health due to the consumption of contaminated food is difficult to assess, and is still controversial. To aid the understanding of potential risks relevant to New Zealand the levels of exposure from food are required. Determination of the levels of microplastics in fresh foods as a result of environmental exposure, e.g. seafood, or a result of processing, will assist in the understanding of the associated risks. In addition, as it is expected that the levels of MPs and NPs, will continue to increase in the environment as a result of continuous addition and fragmentation, it is increasingly important to conduct monitoring over time, particularly of marine species as levels available to, and the route of uptake by fauna, will change over time.

This report identifies some of the potential dietary sources of MPs within New Zealand, based on international studies and identifies the current knowledge gaps. It also highlights future work required to improve the understanding of MPs, and associated risks relevant to New Zealand.

2. INTRODUCTION

Plastics are both pervasive and persistent in the environment, having been found in freshwater, marine and terrestrial environments from the poles to the equator, and from the tops of mountains to the sediments of deep-sea trenches (Eriksen *et al.*, 2013; Eriksen *et al.*, 2014; Graham and Thompson, 2009; Hammer *et al.*, 2012; Horton *et al.*, 2017; Hurley and Nizzetto, 2018; Moore; Rillig *et al.*, 2017; Rios *et al.*, 2007; Taylor *et al.*, 2016; Woodall *et al.*, 2014). The problems associated with large plastic items for marine animals are well known, such as plastic bags that are mistaken as jellyfish and are eaten by turtles. However, it is only recently that the impacts of smaller plastic fragments have been considered, including how they might propagate through the food chain and ultimately affect human health.

Plastic was developed to replace diminishing natural resources. Modern plastics have significantly altered many industries, from the automotive industry to the leisure industry, by allowing the development of items and processes that would otherwise never have been possible with natural materials. The type and use of plastics continues to grow since the development of the first semi-synthetic plastics in the nineteenth century.

Plastic has now become a significant source of pollution and may present a threat to wildlife and humans once its usefulness has come to an end. Unless burnt, which releases large quantities of undesirable substances into the atmosphere, every plastic polymer ever synthesised is still in existence, although possibly broken down into smaller pieces.

Plastics are generally cheap to produce, and consequently plastic items can be made in large quantities and thrown away after a single use. Approximately 300 million tonnes of plastic is produced every year, with 30% being used for disposable items (Geyer *et al.*, 2017; Jambeck *et al.*, 2015). Huge quantities of plastics are therefore destined for landfill, with between 5 and 13 million tonnes (Mt) per year finding its way to the oceans and lakes via rivers and streams when not disposed of properly (Jambeck *et al.*, 2015). Plastic waste from terrestrial sources contributes to the majority of plastics found in the oceans (Andrady, 2011; Fendall and Sewell, 2009; Jambeck *et al.*, 2015). Due to the lightweight nature of plastic items, the majority produced (e.g. plastic bags and bottles) float, allowing them to be transported by the wind and currents. Coupled with the characteristic high level of durability, they are able to travel large distances, impacting all corners of the oceans, not just regions adjacent to large population centres (Clunies-Ross *et al.*, 2016; Desforges *et al.*, 2014; Eriksen *et al.*, 2014; Jambeck *et al.*, 2015; Reisser *et al.*, 2013; Solomon and Palanisami, 2016). It has been estimated that >5 trillion pieces of plastic, weighing >250,000 tonnes are floating in the sea (Eriksen *et al.*, 2014;

Jambeck *et al.*, 2015). Microplastics (fragments 1 µm - 5 mm) are estimated to contribute approximately 14% of that mass (35,000 tonnes) (Cozar *et al.*, 2014; Eriksen *et al.*, 2014; Law and Thompson, 2014). These estimates are based on counts conducted in oceans around the world. However, they are significantly lower than would be expected considering the amounts of plastics produced each year. The missing plastics are thought to have either washed ashore, been swallowed by animals (ultimately posthumously entering the benthic ecosystem) or have sunk to the depths of the oceans due to biofouling by algae and invertebrates, which increases their density. The very buoyant smaller fragments quickly become covered in microbial biofilms (Eich *et al.*, 2015) and are also subject to the processes of flocculation, whereby organic particles clump together forming marine snow which sinks to the seafloor (Woodall *et al.*, 2014).

There are currently no global estimates of MP contamination in terrestrial and freshwater environments, but it is known that both environments are sinks for plastic waste. When plastic undergoes degradation and fragmentation it becomes available for ingestion by a range of biota, providing a potential route into the food chain.

Information on the occurrence and levels of plastic, and associated contaminants, in food and potential health effects in humans were located using the literature database Web of Science (date range: all years to 4th September 2018).

3. HAZARD IDENTIFICATION: PLASTIC POLLUTION

There are a large number of different plastics, made from synthetic or semi-synthetic organic compounds, which have a very broad range of applications (Appendix A). Plastic packaging represents the single largest use of synthetic polymers, with 26% of the total plastic synthesised annually being used for this purpose.[1] In 2013, 78 Mt of plastic packaging was produced worldwide.[2,3] The volume of plastic packaging produced worldwide is expected to continue to grow, doubling within 15 years and more than quadrupling by 2050, to 318 Mt annually – more than the roughly 311 Mt of all plastics currently produced. With total annual plastic production expected to reach 1,124 Mt by 2050, the amount of plastics produced since ca. 1950s will total 33 billion tonnes (Bergmann *et al.*, 2015; Geyer *et al.*, 2017). All types of plastic (Appendix A) may be found in the environment, as well as composites of different plastics such as those used in laminate film and foil packaging. Due to the significant use of plastics in food packaging the five most commonly used plastics, in order of occurrence, are polypropylene (PP: 21%), polyethylene (low-density (LDPE: 20%) high-density polyethylene (HDPE: 16%), polyvinyl-chloride (PVC: 12%), polyethylene terephthalate (PET; 10%) and polyurethane (PUR: 8%). These proportions are reflected in the distribution of plastics collected from the environment and ingested by fauna (e.g. Besseling *et al.*, 2015; Hidalgo-Ruz *et al.*, 2012; Neves *et al.*, 2015; Rios *et al.*, 2007; Rios *et al.*, 2010; Turner and Holmes, 2011) and detected in food (Bouwmeester *et al.*, 2015; Collard *et al.*, 2017a; Collard *et al.*, 2017b; Iniguez *et al.*, 2017; Karami *et al.*, 2017; Schymanski *et al.*, 2018; Van Cauwenberghe *et al.*, 2015; von Moos *et al.*, 2012; Yang *et al.*, 2015). The majority of plastics are synthesised from fossil fuels, but some such as polyethylene (PE), may be made from a plant material feedstock (biobased or biosourced) and have identical chemical properties to crude oil-derived PE. Traditional petroleum-based plastics are not considered biodegradable as their rate of degradation to carbon dioxide, water or methane takes decades to centuries (Cregut *et al.*, 2013; Khan *et al.*, 2017; Shah *et al.*, 2008; Tokiwa *et al.*, 2009; Yoshida *et al.*, 2016). Bioplastics such as polylactic acid (PLA) are synthesised from renewable plant material such as maize, cassava or sugarcane, and, although they share many physical properties of

[1] The New Plastics Economy: Rethinking the future of plastics. World Economic Forum. https://www.newplasticseconomy.org/
[2] Plastics Europe: https://www.plasticseurope.org
[3] Plastic Packaging Market: Global industry Analysis (2015). Transparency Market Research

traditional plastics, are fully compostable, but only under specific conditions, which are not found in the environment.

When they enter the environment plastics are subjected to a range of physical, mechanical and biological degradation processes, resulting in fragmentation which makes them more accessible to uptake by a broad range of fauna at various trophic levels. Fragmentation also makes plastics more pervasive throughout the environment, and increases the probability of contamination of foods during processing.

Plastic debris has been attributed to several different size ranges in different studies but here we will use the following classifications: macroplastics (>20 mm diameter), mesoplastics (5-20 mm diameter), microplastics (MP: 1µm - 5 mm diameter), and nanoplastics (NP: <1 µm) (Andrady, 2011; GESAMP, 2015). MPs and NPs are further characterised into 'primary' and 'secondary' fragments. Examples of food species ingesting plastics from each of these categories have been documented, and therefore all size ranges will be considered here.

Primary nano- and microplastics are those that are manufactured to be a specific size. They typically include microbeads which are used in personal and domestic cleaning products and cosmetics, and nanoparticles used in a broad range of applications such as; medical diagnostics and drug delivery, research applications, 3D printing, adhesives, coatings, and magnetics (Derraik, 2002; Koelmans *et al.*, 2015; Patel *et al.*, 2009; Van Cauwenberghe and Janssen, 2014). They typically enter the environment via wastewater discharge to land or sea (Duis and Coors, 2016; GESAMP, 2015).

Macroplastics include whole plastic items, or the large products of fragmentation and are predominantly food packaging but can be any plastic item that has not been disposed of properly. These items will break down over time due to physical, mechanical and biological activity producing progressively smaller fragments from *secondary mesoplastics*, and ultimately *secondary microplastics* and *nanoplastics* (Andrady, 2011; Browne *et al.*, 2007; Cole *et al.*, 2011; Cooper and Corcoran, 2010; Dawson *et al.*, 2018; Koelmans *et al.*, 2015).

In the oceans >85% of plastic results from land-based activity and is transported to sea by the wind, riverine transport or through wastewater discharge. Plastic is a versatile material for food packaging, and its ease of handling and low cost makes it ideal for mass production of a wide range of products. Polyethylene, polypropylene and polyethylene terephthalate are the synthetic polymers most commonly used in food packaging, and consequently are also the most common polymer type identified in the sea (Besseling *et al.*, 2015; Hidalgo-Ruz *et al.*, 2012; Neves *et al.*, 2015; Rios *et al.*, 2007; Rios *et al.*, 2010; Turner and Holmes, 2011) and

in food and food-species (Bouwmeester *et al.*, 2015; Collard *et al.*, 2017a; Collard *et al.*, 2017b; Iniguez *et al.*, 2017; Karami *et al.*, 2017; Schymanski *et al.*, 2018; Van Cauwenberghe *et al.*, 2015; von Moos *et al.*, 2012; Yang *et al.*, 2015). Many plastics retain some of these chemicals, which may gradually leach out into the environment over time. The remaining plastics found in the ocean are the result of flotsam and jetsam from ships and lost or discarded fishing equipment (Hammer *et al.*, 2012). There are also anecdotal reports of countries deliberately dumping rubbish directly into the sea due to a lack of space in landfill.

Microfibres make up a large proportion of the plastic particles in the oceans (Bosker *et al.*, 2018; Browne *et al.*, 2011; Rochman *et al.*, 2015; Woodall *et al.*, 2014). Originally thought to only be present in the water column, they have more recently been identified as being abundant in sediments (Thompson *et al.*, 2004). In particular, they have been found to occur in deep-sea sediments at concentrations four orders of magnitude greater than in the overlaying surface waters (Woodall *et al.*, 2014). Synthetic clothing is a significant source of these fibres, with the laundering of clothes made from nylon (polyamide), polyester, acrylic (polymethyl methacrylate) and Lycra™ (polyurethane) resulting in more than 100 fibres per litre of wastewater, and polar fleece items generate >180% more fibres per wash than other items of clothing (Browne *et al.*, 2011). These fibres detach from the clothing during laundering and either end up in the solid sludge from wastewater treatment through the process of flocculation, or due to their small size and buoyancy get through filtration and are discharged in the treated wastewater effluent (Browne *et al.*, 2011; Sgier *et al.*, 2016; Zubris and Richards, 2005). Sludge may also be dumped at sea, therefore the trapped fibres become resuspended in the water column, or dumped on land where it has been found that the fibres are able to mobilise from the sludge and travel through the soil (Zubris and Richards, 2005). Fisheries and aquaculture are major sources of synthetic fibres for the environment due to the breakdown of ropes, fishing nets and lines as a result of weathering, biodegradation and general wear and tear.

The presence of plastics pollution (nano-, micro-, meso-, and macro-) in the environment has been revealed as hazardous to animals. While direct effects on biota can occur due to physical disruption (for review see Wright *et al.*, 2013), the indirect effects associated with inherent and adsorbed chemicals contaminants, and adhered microbial pathogens are most relevant in relation to human health risk (Bouwmeester *et al.*, 2015; Thompson *et al.*, 2009; Wright and Kelly, 2017).

3.1 ASSOCIATED CHEMICAL CONTAMINANTS

Plastic polymers are generally considered to be biologically inert, and therefore pose a low health risk to humans. The hazardousness of a plastic is determined based on the hazard classification of its constituent monomers and does not take into account any manufacturing additives and/or degradation products that are released throughout the lifecycle of the plastic.

Manufacturing chemicals

In addition to the monomers, initiators, catalysts and solvents may be used to create the plastic polymers. The relative health risk of virgin plastics (the raw plastic used to manufacture plastic items) is therefore based on the release of hazardous substances during the product lifecycle (Table 1). The additives that are used to modify the nature of the final plastic items, to improve their materials performance and make it suitable for purpose, include stabilisers, plasticisers, flame retardants, pigments and fillers. These chemicals may account for 10-50% of the total weight of the plastic (Andrady, 2017). The chemical additives used in the manufacturing process are dispersed within the polymer structure and can leach from the plastic to the environment over time (Lithner *et al.*, 2011). Leaching rates are dependent upon the molecular size of the additives, the three-dimensional structure of the polymer and the environmental conditions. The plastics may also release monomers post-production, either passively or as a result of weathering (Andrady, 2015). A range of human health risks has been associated with these chemicals (Koch and Calafat, 2009). These chemicals have been found in biota growing on plastics (Jang *et al.*, 2016; 2017) and may enter the food chain. However, it is not known whether they present a dietary risk to humans via this route.

Table 1. Hazard ranking of the six most commonly used plastics (Lithner *et al.*, 2011) and the additives commonly used with them (modified from Hermabessiere *et al.*, 2017).

Polymer Type	Hazard Score*	Additive Types	Hazardous Substances§
Polyethylene (low and high density) (LDPE and HDPE)	11	Antioxidant	Bisphenol A; Octylphenol; Nonylphenol
		Flame retardant	Brominated flame retardants; Boric Acid; Tris(2-chloroethyl)phosphate
Polypropylene (PP)	1	Antioxidant	Bisphenol A; Octylphenol; Nonylphenol

		Flame retardant	Brominated flame retardants; Boric Acid; Tris(2-chloroethyl)phosphate
Polyvinyl chloride (PVC)	10,551 – 5001	Plasticizers	Phthalate
		Stabilizers	Bisphenol A; Nonylphenol
Polyethylene terephthalate (PET)	4	Flame retardant	Brominated flame retardants
Polystyrene (PS)	1628 – 30	Flame retardant	Brominated flame retardants
Polyamide (PA)	63 - 50	Flame retardant	Brominated flame retardant

* The ranking is determined based on the environmental and human health hazard classification of the different constituent monomers and does not take into account any manufacturing additives and/or degradation products that are released throughout the lifecycle of the plastic. The hazard scores, therefore are not absolute values, but are a way to allow an approximate relative ranking, and to highlight the presence of hazardous chemicals. The more hazardous the polymer, the higher it is ranked.

§ Hazardous substances refer to chemicals that pose a risk to the environment and human health as defined by the REACH regulation in the European Union according to the European Chemical Agency (European Chemical Agency, 2017).

Environmental chemicals

The physical and chemical nature of synthetic polymers could also result in the uptake of a large range of chemical contaminants from their immediate environment. Experiments have demonstrated that they have a high affinity for heavy metals (Ashton *et al.*, 2010; Hodson *et al.*, 2017; Holmes *et al.*, 2012; 2014; Munier and Bendell, 2018; Rochman *et al.*, 2014) and hydrophobic organic chemicals (Bakir *et al.*, 2012; Koelmans, 2015; Teuten *et al.*, 2007). An increasing number of studies are identifying the levels of these contaminants associated with MPs in the environment (Goedecke *et al.*, 2017; Hirai *et al.*, 2011; Jang *et al.*, 2017; Mato *et al.*, 2001; Rios *et al.*, 2007; Rios *et al.*, 2010; Zhan *et al.*, 2016). The chemicals include a broad range of types, many of which have been associated with human health effects. For example, 36 polychlorinated biphenyls (PCBs), 17 organochlorine pesticides and 16 US EPA-priority polycyclic aromatic hydrocarbons (PAHs) were found adsorbed to plastics collected from the Northern Pacific Gyre (Rios *et al.*, 2010).

Polymer-type and degree of aging and weathering affects the rate and level of contaminant uptake, with PP and PE found to take up the highest levels of environmental contaminants (Holmes *et al.*, 2012; 2014; Rochman *et al.*, 2013a; Rochman *et al.*, 2014).

Although the degree of bioaccumulation and transfer between trophic levels is not fully understood, organic chemicals found within fish and cetacean tissues correlate to MP ingestion (Fossi *et al.*, 2012; Rochman *et al.*, 2013b) and may be from direct ingestion or indirectly through contaminated prey.

There is continuing debate as to whether microplastics cause an increased risk of transfer of chemical contaminants through the food chain (Bakir *et al.*, 2014a; Bakir *et al.*, 2016; Browne *et al.*, 2013; Carbery *et al.*, 2018; Ziccardi *et al.*, 2016), and there is currently no evidence that there is elevated dietary exposure to these chemicals as a result of MPs. However, the large surface-area-to-volume ratio of MPs represents a highly efficient vector for chemical contaminants in the environment (Bakir *et al.*, 2014b; Chubarenko *et al.*, 2016; Nakashima *et al.*, 2016). Extended residence times observed with microplastic ingestion, coupled with the role of digestive surfactants in increasing the bioavailability by increasing desorption rates up to 30 times greater than in seawater alone (Avio *et al.*, 2015; Bakir *et al.*, 2014a) significantly increases the level of risk to the organisms associated with microplastics. Further research is required to determine the role microplastics play on the transfer of environmental chemical contaminants to humans.

Adsorbed chemicals, such as antibiotics and herbicides, at levels considered below toxic thresholds to humans may present an indirect risk to human health due to their effect on the associated microbial communities (see section 3.2). For example, by influencing microbial pathogen colonisation of the plastics, or increasing the expression of antimicrobial resistance genes (Andersson and Hughes, 2014; Kurenbach *et al.*, 2015).

A single study looking at the levels of contaminants associated with plastic pellets gathered along the coastline of northern New Zealand identified a range of persistent organic pollutants (POPs) adsorbed onto the pellets (Yeo *et al.*, 2015). Polychlorinated biphenyls (PCBs), dichloro-diphenyltrichloroethane and its degradation products (DDTs), and hexachlorocyclohexanes (HCHs) were determined for PE pellets gathered from six locations on the North Island, and demonstrated variation between locations. PCBs concentrations ranged from 0.25 ng g-pellet^{-1} to 157 ng g-pellet^{-1} and significant levels of DDT were found at two sites, Ahipara and Taupa Bay of 23 and 47 ng g-pellet^{-1}, respectively. HCHs concentrations were low at <5 ng g-pellet^{-1} across the six locations examined. Due to levels and type of chemical adsorption, and desorption, varying depending on polymer type and environmental factors, it is important that location-specific analysis is conducted.

3.2 MICROBIOLOGICAL CONTAMINANTS

The unique surface properties of plastics provide a very different physical and chemical environment for the development of microbial biofilms compared to organic material. The plastic-associated microbial communities (the “Plastisphere”) are distinct from both those in the surrounding water and those that form on natural surfaces (Oberbeckmann *et al.*, 2014; Zettler *et al.*, 2013). These communities also demonstrate polymer-specificity as well as geographical, latitudinal and seasonal variation (Amaral-Zettler *et al.*, 2015; Eich *et al.*, 2015; Oberbeckmann *et al.*, 2014).

High buoyancy and resilience of plastics, facilitates the movement of microbial species whose distribution had previously been limited (Derraik, 2002) to be extended. This phenomenon, known as ‘rafting’, has been seen in a range of environmental bacterial pathogens including *Vibrio* (Amaral-Zettler *et al.*, 2015; Harrison *et al.*, 2014; Keswani *et al.*, 2016; Kirstein *et al.*, 2016; McCormick *et al.*, 2014; Zettler *et al.*, 2013) and toxic algae (Maso *et al.*, 2003). Plastics have also been found to facilitate the persistence and transmission of faecal pathogens through wastewater treatment plants (Eckert *et al.*, 2017). Potential human pathogens including *Campylobacter*, *Aeromonas*, *Arcobacter* and *Pseudumonas* were found to be significantly more abundant on plastics relative to ambient levels (McCormick *et al.*, 2014; McCormick *et al.*, 2016).

These new potential substrates provide unique microenvironments for the development of the plastisphere. Due to the high microbial cell densities there is potential for the development of “hot-spots’” of horizontal gene transfer (HGT) (Aminov, 2011; Sezonov *et al.*, 2007). This area of research is in its infancy but preliminary studies have shown that HGT is elevated in the plastisphere (Arias-Andres *et al.*, 2018). Coupled with the ability of microplastics to adsorb and concentrate chemicals such as heavy metals, antibiotics, pesticides and other xenobiotics (Hirai *et al.*, 2011; Koelmans, 2015; Zhan *et al.*, 2016; Ziccardi *et al.*, 2016) which have been found to act as selective agents for antibiotic resistance (Andersson and Hughes, 2014; Heinemann, 1999; Heinemann *et al.*, 2000; Kurenbach *et al.*, 2015; Kurenbach *et al.*, 2017) plastics may act as an accelerant for the occurrence of antimicrobial resistance and transfer of virulence factors (Oberbeckmann *et al.*, 2018). This may be of particular concern with respect to the high levels of MPs and NPs in the environment that originate from wastewater effluent (Petrie *et al.*, 2015; Yu *et al.*, 2018) which have also been exposed to a wide range of chemical contaminants, as well as the high occurrence of potential human pathogens which have been shown to colonise the plastisphere.

To date, it is unknown whether viruses attach to MPs. However, like other microbes, viruses are known to attach to both abiotic and biotic surfaces in the environment, which determine their fate and transport. It would therefore be expected that microplastics would facilitate the survival and transport of potential human viral pathogens through wastewater treatment plants and translocation to the receiving environment (soils or waters), and entry into food-species.

3.3 PLASTICS WITHIN FOOD

3.3.1 Environmental Exposure

Plastics contamination is found in freshwater, marine and terrestrial systems and is found in food intended for human consumption. Contamination of food may result from ingestion by biota, adhesion to the organism's surface in the wild, or during food processing. Uptake resulting from ingestion may be direct or indirect as a result of trophic transfer (Cole *et al.*, 2011; Moore, 2008; Teuten *et al.*, 2009; Welden *et al.*, 2018). Currently it is expected that seafood is the greatest source of microplastics in the diet, however an increasing number of studies are showing their presence in other food sources.

Marine

Plastics have been found in the digestive tract of a wide range of marine organisms around the world (Bellas *et al.*, 2016; Rezania *et al.*, 2018; Smith, 2018). Over 220 different species have been found to ingest MPs (GESAMP, 2015). Fifty eight percent of these species (128/220) are commercially targeted food species, including: fin fish (Akhbarizadeh *et al.*, 2018; Anastasopoulou *et al.*, 2013; Bellas *et al.*, 2016; Boerger *et al.*, 2010; Brate *et al.*, 2016; Cannon *et al.*, 2016; Collard *et al.*, 2015; Collard *et al.*, 2017a; Collard *et al.*, 2017b; Critchell and Hoogenboom, 2018; Foekema *et al.*, 2013; Ghosal *et al.*, 2018; Jabeen *et al.*, 2017; Lusher *et al.*, 2013; Mizraji *et al.*, 2017; Neves *et al.*, 2015; Ory *et al.*, 2018; Pellini *et al.*, 2018; Rummel *et al.*, 2016; Smith, 2018; Tanaka and Takada, 2016; Welden *et al.*, 2018), crustacea (Brennecke *et al.*, 2015; Digka *et al.*, 2018; Farrell and Nelson, 2013; Murray and Cowie, 2011; Watts *et al.*, 2014; Watts *et al.*, 2015; Welden *et al.*, 2018), molluscs (Davidson and Dudas, 2016; Digka *et al.*, 2018; Farrell and Nelson, 2013; Kolandhasamy *et al.*, 2018; Li *et al.*, 2015; Li *et al.*, 2016; Mathalon and Hill, 2014; Santana *et al.*, 2016; Van Cauwenberghe *et al.*, 2015), sea cucumbers (Graham and Thompson, 2009) and seabirds (Ryan *et al.*, 1988; Ryan, 2015; Tanaka *et al.*, 2013). The type of plastic contamination includes a broad range of sizes and morphotypes (fragments, filaments, fibres, films, beads and pellets), and represents both the commonly used polymers and those with specialist uses. The levels of contamination, and therefore risk, are dependent on habitat type and feeding strategy of the species, as well as

the source of plastic contamination. The abundance of MP ingestion has been linked to the presence of human populations, with higher levels nearer to large metropolitan areas (Bellas *et al.*, 2016; Bosker *et al.*, 2018; Neves *et al.*, 2015; Welden *et al.*, 2018) and fishery/aquaculture activity. The breakdown of fisheries and aquaculture gear results in the release of MP fragments and fibres into the environment which can be ingested by wildlife. The types of MPs ingested have been linked to the fishing gear used in the local vicinity (Cole *et al.*, 2011; Jang *et al.*, 2016 ; 2017; Mathalon and Hill, 2014), and elevated levels have been associated with increased fishing or aquaculture activity (Castro *et al.*, 2016; Lusher *et al.*, 2013; Mathalon and Hill, 2014; Murray and Cowie, 2011).

To date, no studies have been carried out to determine the levels of micro- or nanoplastics contamination, or the associated risk factors (chemical and microbiological) in New Zealand food species.

Fin fish

Research has found that a large variety of commercially important fish species is often contaminated with microplastics (for a comprehensive list of species investigated see Barboza *et al.*, 2018a) but generally have been found to have the lowest levels of direct ingestion. MP ingestion is linked to behaviour and habitat type (Bellas *et al.*, 2016; Ory *et al.*, 2018; Rochman *et al.*, 2015). Species that live in close contact with the seafloor are thought to be at greatest risk of contamination by MPs due to their interactions with the sediments (Bellas *et al.*, 2016; Neves *et al.*, 2015; Rummel *et al.*, 2016). The main focus, to date, has been determination of plastics within the gastrointestinal tract of fin fish and it was considered that as fin fish species are usually gutted before eating, the risk of dietary exposure to MPs from this source is likely to be negligible. Although, the risk of any contaminants that have bioaccumulated following desorption from the MPs will remain (Akhbarizadeh *et al.*, 2018). However, recent studies have identified plastic fragments, mostly fibres, within muscle tissue (Abbasi *et al.*, 2018; Akhbarizadeh *et al.*, 2018). The process by which these fragments are able to translocate to the muscle remains unknown (Akhbarizadeh *et al.*, 2018).

Fish that may be eaten whole (anchovies, sardine or fry/whitebait of larger species) present a risk of transfer of MPs present in the fish gut. Anchovies and sardines and larval fish are planktivorous filter-feeders, and have been found to ingest MPs (Collard *et al.*, 2017a; Collard *et al.*, 2017b; Digka *et al.*, 2018; Mazurais *et al.*, 2015; Sun *et al.*, 2017). To date no studies have examined the uptake of NPs or MPs by New Zealand whitebait/īnanga (*Galaxias maculatus*), which are eaten whole.

The main focus of plastic contamination in fin fish has been on the microplastic size range. However, a recent study has identified that fin fish may ingest NPs via their prey as a result of trophic transfer (Chae *et al.*, 2018). The particles were also found to translocate from the gut and concentrate in the liver and brain. Therefore, evisceration may not remove all risks associated with MP contamination. It must be noted that although these experimental species were not food species the principle of trophic transfer of NPs, and organ translocation is relevant to other higher trophic level fish species, for example trout.

Bivalve molluscs

There is a growing number of publications on the occurrence of MPs in marine molluscs. Bivalves take up MPs whilst filter-feeding (Davidson and Dudas, 2016; Digka *et al.*, 2018; Farrell and Nelson, 2013; Kolandhasamy *et al.*, 2018; Li *et al.*, 2015; Li *et al.*, 2016; Mathalon and Hill, 2014; Santana *et al.*, 2016; Van Cauwenberghe *et al.*, 2015), with recent reports suggesting that MPs may also become associated with the flesh through adhesion (Kolandhasamy *et al.*, 2018). In general, study sample sizes are small and *in natura* studies are restricted to Europe, North America, Brazil and China. Levels of MPs ranged from <0.5 to 35 particles per gram of soft tissue (Table 2). Fragment sizes ranged from 5 µm to 5 mm, representing all morphotypes, predominantly of polyethylene and polystyrene, have been identified from both wild and farmed bivalves.

Due to methodology limitations the levels and type of NPs have not been assessed in bivalves, but experimental studies have shown that bivalves also ingest NPs (Browne *et al.*, 2008; Canesi *et al.*, 2012; Farrell and Nelson, 2013; Koehler *et al.*, 2008; Santana *et al.*, 2017; Sussarellu *et al.*, 2016; Ward and Kach, 2009) despite them being below their prey size. Once ingested these NPs may cross cell membranes, and enter the bloodstream and organs, resulting in a longer retention time than larger MP particles (Farrell and Nelson, 2013; Santana *et al.*, 2017; Ward and Shumway, 2004).

Bivalve molluscs are thought to present the highest risk of MP ingestion due to the custom of eating them whole. The per capita consumption of molluscs in New Zealand is 440 g capita^{-1} yr^{-1} (Cressey, 2013). Using the average range of MP load detected in mollusc species (2.1 – 10.5 particles g^{-1} soft tissue) (Rist *et al.*, 2018) the dietary exposure to MPs through bivalves can be between 924 and 4620 MP fragments per capita per year. This does however only provide a rough estimate for MP loads in mussels in New Zealand as there are currently no data available for the levels of MPs in mussels grown in New Zealand waters. In comparison, in Europe, where there has been significant investment in the assessment of MPs in seafood,

it has been estimated that in European countries with high shellfish consumption it is likely consumers ingest up to 11,000 MP particles (5 – 1000 µm) per year (Van Cauwenberghe and Janssen, 2014).

Table 2. Occurrence of microplastics in species of bivalve molluscs (modified from Lusher *et al*., (2017)**.**

Species[a]	Location	Average number of particles per g soft tissue	Morphotype	References
M. edulis	Germany	0.36 (0.07); n = 72 Size: 5–25 µm (85%), > 25 µm (15%)	Fragments, spheroids	(Van Cauwenberghe and Janssen, 2014)
C. gigas		0.47 (0.16); n = 21 Size: 5–25 µm (55%), > 25 µm (45%)		
M. edulis	Belgium France Netherlands	0.20 (0.30); n = 6 Size: 20–90 µm	Fragments	(Van Cauwenberghe *et al.*, 2015)
M. edulis	Belgium	0.37 (0.22); n = 9 Size: 200–1500 µm	Fibres	(De Witte *et al.*, 2014)
M. edulis	Newfoundland	34 (14)[b]; n = 45 Size: no data	Fibres, spheroids	(Mathalon and Hill, 2014)
M. edulis	China	2.2 (0.9–4.6)[c]; n~1100 Size: 33–4700 µm (fibres)	Fibres, fragments	(Li *et al.*, 2016); (Kole *et al.*, 2017)
9 different species	China	4.0 (2.1–10.5)[d]; n = 9 Size: 5–250 µm (60%), 250–5000 µm (40%)	Fragments, fibres, pellets	(Li *et al.*, 2015)
P. perna	Brazil	75% contained ≥ 1 particle; n = 30 Size: < 5000 µm	Fragments	(Santana *et al.*, 2016)
V. philippinarum	British Colombia	Wild: 0.84 (0.85) Farmed: 1.13 (0.66) n= 54 Size: no data	Fibres, films, fragments	(Davidson and Dudas, 2016)

[a] *M. edulis – Mytilus edulis (*Blue mussel)*; C. gigas – Crassostrea gigas* (Pacific oyster)*; P. perna – Perna perna* (Brown mussel), *V. philippinarum – Venerupis philippinarum* (Manila clam); [b] only microfibres, spherical particles not quantified, values calculated from Mathalon and Hill (2014) using a weight of 4 g of soft tissue per mussel; [c] average and range; [d] median and range.

Gastropod molluscs

There is very little information available on the uptake of MPs by grazing gastropods. One study has shown that the intertidal snail *Littorina littorea* ingests MPs that are associated with the surface of the algae they graze on (Gutow *et al.*, 2016). MP particles were recovered from their gut and stomach, and were present in their faecal pellets indicating that MPs do not accumulate in the gut, although gut retention time may result in the potential for human ingestion. In New Zealand, the majority of common gastropods recreationally gathered are eaten whole, and therefore present a potential route of contamination (e.g. Cat's Eye/pūpū; *Turbo smaragdus*). The gut/hua is normally removed from pāua before consumption, but is considered a delicacy by some Māori and eaten in preference to the foot meat.

Crustaceans

Crustaceans have been found to ingest MPs although studies are limited. *In natura* study of the Norwegian lobster (*Nephrops norvegicus*) and spider crab (*Maja squinado*) found of those individuals tested that 83% and 42%, respectively, contained MPs within their guts, comprised predominantly of different types of fibres in entangled balls (Murray and Cowie, 2011; Welden *et al.*, 2018). Fibres were also found to be the predominant MP-type associated with tiger prawns (*Penaeus semisulcatus*), and were isolated from both the gut, and non-digestive organs (Abbasi *et al.*, 2018). Challenge experiments of the Norwegian lobster and other species demonstrated that MP and NP uptake occurred through trophic transfer from their prey (Farrell and Nelson, 2013; Murray and Cowie, 2011; Santana *et al.*, 2017). MP particles have been found in multiple organs, including the gills, stomach and hepatopancreas (Brennecke *et al.*, 2015; Watts *et al.*, 2014).

The study of NPs uptake in crustaceans is limited. To date a single study of Antarctic krill (*Euphausia superba*) identified that NPs were capable of crossing biological barriers and entering the haemolymph (Dawson *et al.*, 2018). There have been no studies of NPs in food-species of crustacea.

The risk of ingestion of MPs from crustaceans is not known. However, due to the normal practice of removal of the digestive tract before consumption it would be expected that dietary exposure would be avoided. With respect to NPs, evidence of their ability to migrate from the gut into haemolymph raises the possibility of dietary exposure (Farrell and Nelson, 2013).

Other invertebrates

Limited research has examined the ingestion of plastic contamination by sea cucumbers and sea urchins. Sea cucumbers have been found to feed on MP particles in preference to organic material, and show differences in ingestion due to feeding strategy (Graham and Thompson, 2009). Experimental studies have demonstrated that the larval stage of sea urchin/kina will ingest NPs (Della Torre *et al.*, 2014), but no studies have demonstrated the *in natura* uptake of micro- or nanoplastics in adults.

There is currently no research on the uptake of plastic contamination by cephalopods, e.g. squid, or octopus

Seabirds

Seabirds are susceptible to plastic ingestion, and are a source of protein in several countries around the world. In New Zealand the shearwater nestlings of two species (*Puffinus griseus* and *P. huttoni*, common name: muttonbird/tītī) are considered a taonga. Those gathered around Stewart Island (Rakiura) and the adjacent Tītī Islands are sold throughout the country. Shearwaters feed on fish, squid, krill and other invertebrates in the surface waters. They are indiscriminate feeders and therefore inadvertently feed on plastics, although there is a growing body of evidence to suggest that they selectively feed on plastics due to the release of chemicals during weathering and from the biofilms that form on them (Rummel *et al.*, 2017; Savoca *et al.*, 2016). During the breeding season adults feed in local waters, returning to their young where they regurgitate the feed, including plastics (Buxton *et al.*, 2013). Whilst the intestinal tract is removed from the juvenile birds before consumption plastic-associated chemicals have been found to transfer to their tissues (Ryan *et al.*, 1988; Tanaka *et al.*, 2013; Teuten *et al.*, 2009). However, it must be acknowledged that it is not fully understood whether the ingestion of plastics amplifies the uptake of chemical contaminants, above the exposure from their natural food intake (Bakir *et al.*, 2016). They may also ingest MPs and NPs through trophic transfer (Barboza *et al.*, 2018b; Cedervall *et al.*, 2012; Chae *et al.*, 2018; Cole *et al.*, 2015; Collard *et al.*, 2017a; Collard *et al.*, 2017b; Dawson *et al.*, 2018; Della Torre *et al.*, 2014; Sun *et al.*, 2017). The mobility of NPs into tissues provides the potential that they may transfer to the edible tissues of the tītī (Chae *et al.*, 2018; Farrell and Nelson, 2013; Mattsson *et al.*, 2017).

Terrestrial

The study of plastics within the terrestrial environment is limited. MPs enter the soil through the physical and mechanical degradation of large plastic items, aerial deposition, irrigation

water contaminated with MPs, from agricultural and horticultural activities (Ng *et al.*, 2018; Rillig *et al.*, 2017; Schirmel *et al.*, 2018; Weithmann *et al.*, 2018) or by sewage sludge and effluent deposition (Browne *et al.*, 2011; Duis and Coors, 2016; Nizzetto *et al.*, 2016; Zubris and Richards, 2005).

Recent research has concentrated on the impacts of micro- and nanoplastics on soil fauna (Lwanga *et al.*, 2016; Maaß *et al.*, 2017; Machado *et al.*, 2018; Ng *et al.*, 2018), and studies have shown that plant cells are able to take up polystyrene NPs by endocytosis (Bandmann *et al.*, 2012). However, to date, there have been no studies of the uptake by food-species which may act as a route for MP and NP contamination for humans.

Freshwater

Rivers, streams, lakes and groundwater systems may become contaminated through the improper disposal of plastic items, the use of agricultural and horticultural plastics (Ng *et al.*, 2018; Rillig *et al.*, 2017; Schirmel *et al.*, 2018), and the disposal of wastewater effluent (treated and untreated) directly into the ecosystems (Browne *et al.*, 2011; Duis and Coors, 2016; Nizzetto *et al.*, 2016; Zubris and Richards, 2005), or run-off from land (Auta *et al.*, 2017; Baldwin *et al.*, 2016; Novotny *et al.*, 2009).

MPs have been identified in rivers, streams and lakes around the world (Eriksen *et al.*, 2013; Hurley *et al.*, 2018; McCormick *et al.*, 2016; Wang *et al.*, 2017; Zhang *et al.*, 2016). Ingestion has been reported in freshwater fish (Jabeen *et al.*, 2017; Sanchez *et al.*, 2014), but to date there have been no reports of the presence of plastics within freshwater food species.

No studies have yet analysed the transport of microplastics into groundwater, although transport through biopores, burrows and the organisms that live within the soils have been identified as a potential mechanism for groundwater contamination (Hodson *et al.*, 2017; Hurley and Nizzetto, 2018; Lwanga *et al.*, 2016; 2017; Maaß *et al.*, 2017) which may provide a direct or indirect route to the human diet.

3.3.2 Processed Food

Seafood is considered the main source of MP contamination in the diet, however processed foods offer another route. The presence of MPs in German beer was investigated in 2014. It was found that MPs (fibres, fragments and granules) were present in 24 German beer brands (Liebezeit and Liebezeit, 2014), with the levels ranging from 2 - 79 litre^{-1}, 12 - 109 litre^{-1} and from 2 - 66 litre^{-1}, respectively. These plastics were thought to originate from the production process and not from environmental pollution. A more recent study investigated the levels of

MPs in twelve bands of American beer (Kosuth *et al.*, 2018), which were all made using water drawn from the Laurentian Great Lakes which have previously been demonstrated to contain high levels of microplastics (Eriksen *et al.*, 2013). MPs were found in all 12 brands that were tested, with particle number ranging from 0 to 14.3 litre^{-1}, with an overall mean of 4.05 litre^{-1}. A total of 198 particles were isolated, the majority of which were fibres. As part of the study they also sampled the corresponding tap water that was used in production of the beer, however no correlation was found between the MP content of the beer and the water.

MPs have been identified in honey (Liebezeit and Liebezeit, 2013), however this is an isolated study. Honeys from Germany, France, Italy, Spain and Mexico were all found to contain coloured fibres and fragments which were thought to have been introduced to the hive by the bees, where they have contaminated the honey. Fibres (40 µm to 9 mm) were most common, ranged from 40 to 660 kg^{-1} of honey, whereas fragments (10−20 µm) were considerably less abundant (0−38 kg^{-1} of honey).

Fibres and fragments have also been found in commercial sugars (Liebezeit and Liebezeit, 2013). Unrefined cane sugar contained 560 fibres and 540 fragments kg^{-1}. Refined sugar contained a lower level of contamination, with fibres (mean 217 ± 123 kg^{-1} of sugar) and fragments (32 ± 7 kg^{-1} of sugar).

Table salt from multiple countries, including New Zealand, has been examined for the presence of MP contamination (Iniguez *et al.*, 2017; Karami *et al.*, 2017; Kosuth *et al.*, 2018; Yang *et al.*, 2015). MPs were found in well salt, sea salt and lake salt, with the highest levels found in sea salt from China and the South Pacific, which had 550−681 particles kg^{-1} and 440 – 1020 particles kg^{-1}, respectively. Fibres were the most common morphotype found in these studies, with polyethylene terephthalate the predominant polymer. The New Zealand sea salt had one of the lowest levels of contamination, with a single polypropylene fragment found per kg of salt (Karami *et al.*, 2017). As the packaging material was composed of polyethylene it was concluded that the contamination originated from the sea water, and not the packaging process.

The presence of NPs has not been examined in any processed food items.

3.3.3 Drinking water

MPs have been found in drinking water. Analysis of bottled water in Germany found that all bottle types analysed contained MP contamination (Schymanski *et al.*, 2018). The number of plastic particles in water from returnable plastic bottles were in the range 2 - 44 particles l^{-1}; 8

times higher than from water in single-use plastic bottles and nearly 10 times higher than that from beverage cartons. Most of the particles in water from returnable plastic bottles were identified as consisting of polyethylene terephthalate (PET; 84%) and polypropylene (PP; 7%). This is not surprising, since the bottles are made of PET and the caps are made of PP. It is thought that returnable bottles contained high levels of these plastics due to the physical stress the bottles are put under during reutilisation. Glass bottles were also found to contain MPs (50 ± 52 particles l^{-1}), which are thought to originate from the plastic lids. Analysis of tap water from 14 countries (Kosuth *et al.*, 2018) identified plastic fragments in 81% of the 126 samples tested. The range in MP particle number within all samples ranged from 0 to 61 particles litre[1], with an overall mean of 5.45 particles litre^{-1}. New Zealand was not included in this study.

The presence of NPs has not been examined in bottled, or tap water or drinking water sources (e.g. aquifers, reservoirs).

3.4 EXPOSURE ASSESSMENT

Whilst there have been numerous studies examining the risk of microplastics to wildlife (Hermabessiere *et al.*, 2017) the consequences to human health should plastics be transferred through the food chain are unclear and require further investigation (Law and Thompson, 2014). Seafood has already been clearly identified as a potential route of plastics, and associated chemical contaminants, into the human diet with a growing body of literature demonstrating the presence of nano- and microplastics in commonly eaten marine species, such as mussels, oysters, fish, sea cucumbers and lobsters (e.g. Avio *et al.*, 2015; Browne *et al.*, 2008; Cannon *et al.*, 2016; Dehaut *et al.*, 2016; Graham and Thompson, 2009; Li *et al.*, 2015; Murray and Cowie, 2011; Rochman *et al.*, 2015; Santana *et al.*, 2016; Sussarellu *et al.*, 2016; Van Cauwenberghe and Janssen, 2014; Van Cauwenberghe *et al.*, 2015). Other foods that have been shown to contain MPs include table salt, honey, sugar and beer (Bouwmeester *et al.*, 2015; Gassel *et al.*, 2013; Iniguez *et al.*, 2017; Karami *et al.*, 2017; Yang *et al.*, 2015). The presence of microplastic particles in drinking water (Schymanski *et al.*, 2018) may also provide a source of contamination to a broad range of foods through its use in processing. More recently there is evidence to suggest that groundwater has the potential to become contaminated by the land disposal of wastewater effluent and biosolids and horticultural plastics (Schirmel *et al.*, 2018). In areas where water from a groundwater source is used in the growth or preparation of food it provides a source of MP and NP contamination within food.

Considerably more is known about the human health risks of the chemicals that are found to concentrate on the plastics. Although these may be present at relatively low levels in lower

trophic level organisms they may biomagnify up the food chain. Humans eat seafood from all trophic levels, from detritus feeding sea cucumbers (Graham and Thompson, 2009) that have been found to accumulate plastics in high numbers, to higher trophic level species such as swordfish that are known to contain higher levels of persistent organic pollutants and heavy metals. Therefore, the enhanced bioaccumulation and biomagnification of these toxins, facilitated by the ingestion of microplastics, may pose a greater threat to human health through our diet. To date, no study has tracked the fate of MPs/NPs and their associated chemical contaminants through complex marine food webs. Furthermore, there has been no attempt to understand their transfer from seafood to humans and the implications for human health.

The preferential association of potential human pathogens on microplastics (Keswani *et al.*, 2016; Kirstein *et al.*, 2016) means that their presence in the environment and uptake by food species may act as a new vector for pathogens to humans, however this research is in its infancy. With the high prevalence of microplastics within aquatic sediments and water columns it is important to understand how they interact with potential pathogens, and their potential to be incorporated into the food chain.

Whilst there is clear evidence that microplastics are entering the food chain and that some of the chemical contaminants that have been found adsorbed to them are known to have significant human health effects, significant knowledge gaps exist. More research is required to determine both the level and degree of risk associated with the consumption of different food types by humans.

There are currently no data on the level and type of plastic contamination that may be taken up by food-species in New Zealand, or the levels or type of associated contaminants (microbial and chemical).

3.5 HAZARD IDENTIFICATION CONCLUSION

Due to the limited numbers of studies looking at MPs in food products and beverages it is not possible to quantify the dietary intake of MPs. Based on the few published studies it is estimated that a maximum exposure per person per year from sea salt would be 37–1000 plastic particles (Karami *et al.*, 2017; Yang *et al.*, 2015), 4000 from tap water (Kosuth *et al.*, 2017) and 11,000 from shellfish (Van Cauwenberghe and Janssen, 2014).

As the level of plastics in the environment increases it is probable that plastic contamination in foods will also continue to grow in the foreseeable future. The continual fragmentation of plastic debris will shift the particle distribution from larger plastics into smaller micro- and

nanoplastics, with a continuously increasing number of smaller particles. Therefore, the probability of uptake of nano- and microplastics, and potential levels of both direct and indirect contamination (microbial and chemical associates), will increase. The increase in smaller fragments also increases the chance of plastic contamination entering the food web at a lower level, allowing greater trophic transfer and biomagnification. It is therefore important to understand the levels of plastic contamination in the environment and biota to determine the potential levels of ingestion by humans.

4. INITIATIVES AND ASSESSMENTS

The European project 'ECsafeSEAFOOD'[4] is part of the FP7 Programme (Cooperation, Food, Agriculture and Fisheries, and Biotechnology in Europe, which includes 18 partners from 10 European countries. This programme focuses on the health risk from seafood in relation to priority contaminants including MPs.

As part of the Convention for the Protection of the Marine Environment of the North-East Atlantic (the 'OSPAR Convention') the International Council for the Exploration of the Seas (ICES) has developed protocols for monitoring plastic particles in fish and shellfish[5] within the North-East Atlantic region.

The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)[6] provides advice to United Nations organisations on the pressures affecting the marine environment. Working Group 40: *Sources, Fate and Effects of plastics and micro-plastics in the marine environment*, develop guidelines and monitoring protocols, as well as manage monitoring programmes to assess the occurrence and effects of nano- and microplastics on marine organisms. This information is then used to make research and policy-relevant recommendations.

[4] http://www.ecsafeseafood.eu
[5] http://www.ices.dk
[6] http://www.gesamp.org

5. CONCLUSIONS

5.1 DESCRIPTION OF RISKS TO NEW ZEALAND CONSUMERS

An increasing number of studies are identifying the levels of plastic contamination in food-species and processed food items. However, it is not possible to determine the level of risk as the data are currently still too fragmentary, even at the global scale, to perform an acceptable dietary exposure assessment. Apart from fish and shellfish, foods from terrestrial sources might possibly also contribute to the human MP exposure, and data on these foods are emerging.

There is very limited information about MPs/NPs contamination of food in New Zealand. To date, a single study has examined a single food item produced in New Zealand (sea salt) (Karami *et al.*, 2017) which was found to contain fragments of plastic. The polymer-type did not match that of the packaging material suggesting that the source was not related to packaging process. Due to differences in MP uptake by different biota, as well as variation in the occurrence of MPs in the environment, a comprehensive study of the levels and types of MPs contamination (and associated risk factors) in New Zealand would be required to allow the assessment of the dietary exposure.

5.2 KNOWLEDGE GAPS

The levels of plastic contamination in processed food and food-species in New Zealand are currently not known, with the exception of a single limited study of sea salt. The levels of plastics, as well as polymer type and associated chemical and microbial contaminants should be determined to help ascertain the dietary intake of this contamination.

The area of MPs research is still in its infancy, and although there is a growing number of studies examining the levels of plastics in the environment, food-species, and processed foods the data available are patchy and does not allow assessment of the dietary risk.

There are no data on the fate of plastics following ingestion by humans or the associated contaminants they may carry or the potential impacts that cooking and/or processing of food at high temperatures may have on their toxicity.

5.3 FUTURE RESEARCH

In order to understand the risks of MPs (and NPs) for consumers in New Zealand the following research is required:

- Initial work is required to understand the levels of MPs in the New Zealand environment, in particular the marine system as it has been identified in international studies that the consumption of contaminated seafood is the greatest dietary source of MPs. It would be beneficial to conduct a comprehensive assessment of MPs across New Zealand including different marine components, to enable detection of potential spatial and temporal variation.

- The level of MPs in the edible tissues of fish and shellfish consumed in New Zealand, and exported overseas should be quantified. In addition, it would be beneficial to quantify those present in non-edible parts due to the increasing evidence of indirect effects of MPs, such as vectors for chemical toxins.

- It is expected that the levels of MPs and NPs, will continue to increase in the environment due to the continued addition and fragmentation of the plastics present. It is therefore important long-term to assess changes in the levels of both nanoplastics and microplastics in the environment and seafood, due to the differences between uptake and exposure routes of the two size classes.

- The levels of MPs in foods processed in New Zealand, and the water used in processing or manufacture, should be examined.

- The potential chemical and microbiological hazards and risks associated with MPs specific to New Zealand should be determined.

- Develop analytical methods for the quantification and identification of NPs in the environment and food/drink, thereby generating a better understanding of exposure levels and human health risks.

- Trophic transfer studies are required to determine the capacity for MPs/NPs to transfer contaminants through marine food webs, facilitating the bioaccumulation and biomagnification of microplastics and associated contaminants in higher trophic order food species.

- The impact cooking has on the desorption and subsequent bioaccessibility of contaminants associated with MPs/NPs is required to better understand the implications for human health.

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APPENDIX A: SYNTHETIC POLYMERS, RISK SCORES AND COMMON USES

Table 3. Common synthetic polymers and examples of items produced from them.

Polymer	Abbreviation	Hazard Score* (highest level)	Uses
Polyamide	PA or Nylons	Nc	Fibres, toothbrush bristles, tubing, fishing line and low-strength machine parts such as engine parts or gun frames.
Polycarbonate	PC	1177	Compact discs, eyeglasses, riot shields, security windows, traffic lights and lenses.
Polyester	PES	1414	Fibres and textiles.
Polyethylene	PE	11	A wide range of inexpensive uses including supermarket bags and plastic bottles.
High-density polyethylene	HDPE	11	Detergent bottles, milk jugs and moulded plastic cases.
Low-density polyethylene	LDPE	11	Outdoor furniture, siding, floor tiles, shower curtains and clamshell packaging.
Polyethylene terephthalate	PET	4	Carbonated drinks bottles, peanut butter jars, plastic film and microwavable packaging.
Polypropylene	PP	1	Bottle caps, drinking straws, yogurt containers, appliances, car fenders (bumpers) and plastic pressure pipe systems.
Polystyrene	PS	30	Foam peanuts, food containers, plastic tableware, disposable cups, plates, cutlery, compact-disc (CD) and cassette boxes.
High impact polystyrene	HIPS	1628	Refrigerator liners, food packaging and vending cups.
Polyurethanes	PU	13,844	Cushioning foams, thermal insulation foams, surface coatings and printing rollers: currently the sixth or seventh most commonly-used plastic, for instance the most commonly used plastic in cars.

Polyvinyl chloride	PVC	10,551	Plumbing pipes and guttering, shower curtains, window frames and flooring.
Polyvinylidene chloride	PVDC	Nc	Food packaging, such as: Saran
Acrylonitrile butadiene styrene	ABS	6552	Electronic equipment cases (e.g. computer monitors, printers, keyboards) and drainage pipe.
Polycarbonate/Acrylonitrile Butadiene Styrene[TP]	PC/ABS	Nc	A blend of PC and ABS that creates a stronger plastic used in car interior and exterior parts, and mobile phone bodies.
Polyethylene/Acrylonitrile Butadiene Styrene	PE/ABS	Nc	A slippery blend of PE and ABS used in low-duty dry bearings.

*****The hazard score is determined based on the environmental and human health hazard classification of the different constituent monomers and does not take into account any manufacturing additives and/or degradation products that are released throughout the lifecycle of the plastic. The hazard scores, therefore, are not an absolute value, but are a way to allow an approximate relative ranking, and to highlight the presence of hazardous chemicals. The more hazardous the polymer, the higher it is ranked. Nc: not classified.

Table 4. Synthetic polymers used for specialist applications.

Polymer	Abbreviation	Hazard Score* (highest level)	Uses
Polyepoxide	Epoxy	7139	Used as an adhesive, potting agent for electrical components, and matrix for composite materials with hardeners.
Polymethyl methacrylate	PMMA or Acrylic	1021	Contact lenses (of the original "hard" variety), glazing (best known in this form by its various trade names around the world; e.g. Perspex, Plexiglas, Oroglas), aglets, fluorescent light diffusers, rear light covers for vehicles.
Polytetrafluoroethylene	PTFE or Teflon	Nc	Used for heat-resistant, low-friction coatings, used in things like non-stick surfaces for frying pans, plumber's tape and water slides.
Phenolics or phenol formaldehyde	PF	1450	Used for insulating parts in electrical fixtures, paper laminated products (e.g. Formica), thermally insulation foams. It can be moulded by heat and pressure when mixed with a filler-like wood flour or can be cast in its unfilled liquid form or cast as foam. Trade name Bakelite.
Melamine formaldehyde	MF	882	Used in break-resistance alternatives to ceramic cups, plates and bowls for children and the decorated top surface layer of the paper laminates such as Formica.
Urea-formaldehyde	UF	750	One of the aminoplasts, used as a multi-colorable alternative to phenolics: used as a wood adhesive (for plywood, chipboard, hardboard) and electrical switch housings.
Polyetheretherketone	PEEK	Nc	Strong, chemical- and heat-resistant, biocompatibility allows for use in medical implant applications, aerospace mouldings.
Maleimide/bismaleimide		Nc	Used in high temperature composite materials.
Polyetherimide	PEI or Ultem	Nc	A high temperature, chemically stable polymer that does not crystallize

Polyimide	PI	Nc	A high temperature plastic used in materials such as Kapton tape.
Plastarch material		Nc	Biodegradable and heat-resistant thermoplastic composed of modified corn starch.
Polylactic acid	PLA	Nc	A biodegradable, thermoplastic used in single-use items. Most commonly used compostable biopolymer.
Furan		Nc	Resin based on furfuryl alcohol used in foundry sands and biologically derived composites.
Silicone		Nc	Heat resistant resin used mainly as a sealant but also used for high temperature cooking utensils and as a base resin for industrial paints.
Polysulfone		Nc	Used in membranes, filtration media, water heater dip tubes and other high temperature applications.

* The hazard score is determined based on the environmental and human health hazard classification of the different constituent monomers and does not take into account any manufacturing additives and/or degradation products that are released throughout the lifecycle of the plastic. The hazard scores, therefore, are not an absolute value, but are a way to allow an approximate relative ranking, and to highlight the presence of hazardous chemicals. The more hazardous the polymer, the higher it is ranked.. Nc: not classified.

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