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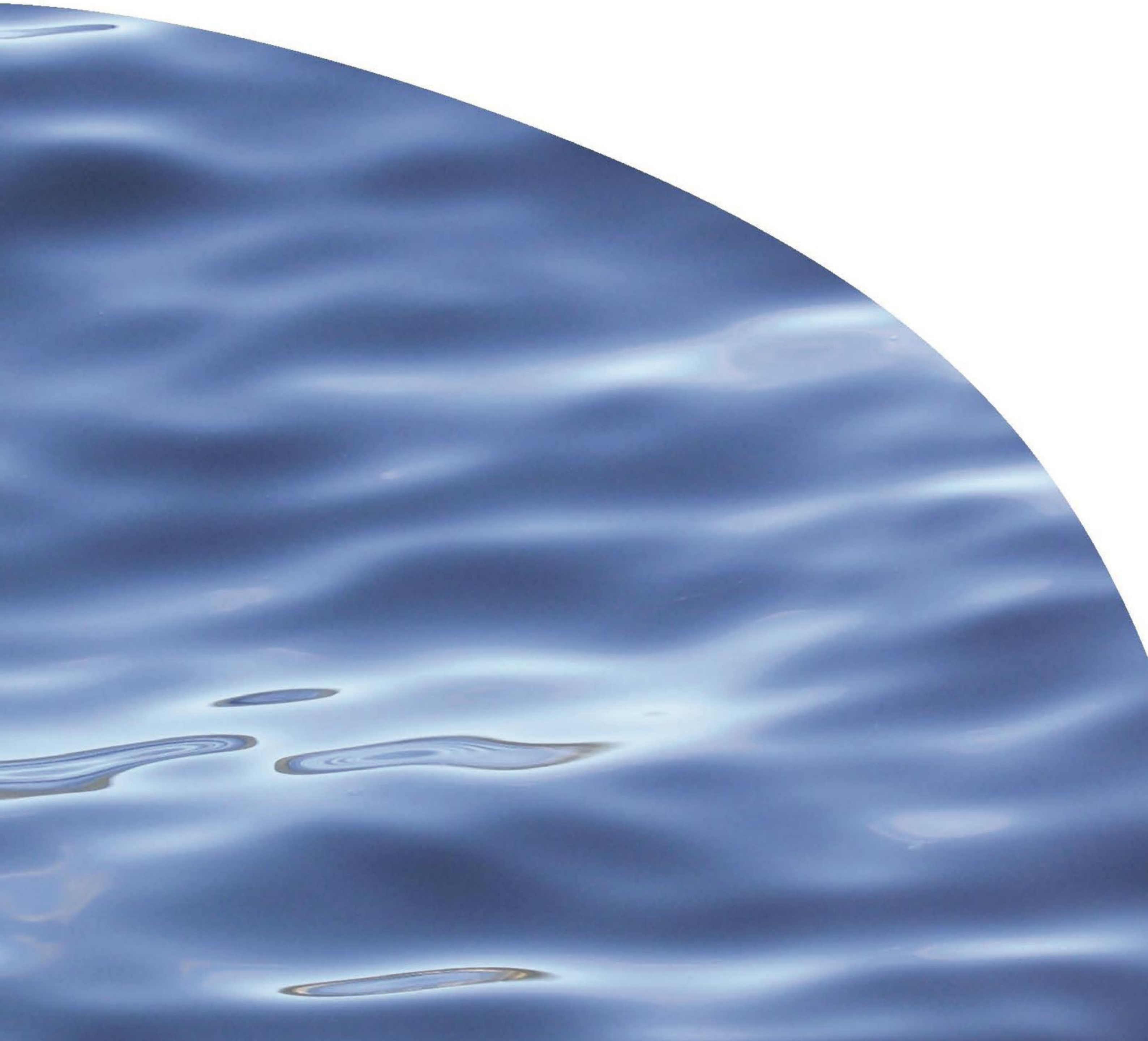

A REVIEW OF MICROPLASTICS RISK – IMPLICATIONS FOR ENVIRONMENT SOUTHLAND

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1. INTRODUCTION

There is increasing scientific and public concern over the presence and persistence of plastic pollution in the environment. An estimated 5 to 13 million metric tons of plastics enter the oceans annually, and that amount is projected to continue to increase if no mitigation measures are put in place (Burgess & Ho 2017). This is an environmental issue that must be addressed and managed by regional councils. This report was commissioned by Environment Southland to focus on the ecological risk assessment related to microplastics in the environment. It provides an overview of current state of knowledge information to assist Environment Southland to develop risk mitigation and management strategies for plastics and microplastics (defined in Section 2).

Research on marine plastic pollution has been the focal point of scientists, the public and policy makers. However, recent literature on the presence of *microplastics* in air, soil, sediments, freshwaters, oceans, plants, animals, and parts of the human diet, raise broad concerns of the impacts of plastics and microplastics in complex global ecosystems. It is established that microplastics are a ubiquitous contaminant and their impacts in the environment pose the highest risk from plastic pollution. Plastic debris is usually divided into two categories: macroplastics > 5 mm and microplastics greater than 0.3 mm and less than 5 mm (Moore 2008). The presence of microplastics in all environmental compartments (water, soil, air, and biota) has gained increasing public and political awareness along with the desire to identify sources and reduction / remediation options (Vollertsen & Hansen 2017). The limited investigations completed to date in New Zealand indicate the types and concentration of microplastics entering and persisting in our environment are likely to be similar to those reported in many other countries.

The objectives of this report were to:

- review the national and international research literature on the sources of microplastics, their fate and transport in the environment and current state of knowledge on their risk to ecosystem and human health
- summarise the international research programmes and strategies to assess, characterise and manage the risk of microplastics
- cover current international guidelines and legislation including initiatives to reduce or eliminate plastics and ultimately microplastics
- provide a list of current microplastics research efforts in New Zealand
- provide recommendations to define knowledge gaps and research needs to better manage the risk of microplastics in New Zealand.

2. WHAT ARE MICROPLASTICS?

2.1. Definition

Microplastics come from the partial degradation of plastic material. Plastic has been defined as a synthetic organic water-insoluble polymer, generally of petrochemical origin, that can be moulded on heating and manipulated into various shapes designed to be maintained during use (Burns & Boxall 2018). This definition includes both thermoplastics, such as polyethylene and polypropylene, and thermoset plastics (i.e., cannot be remoulded after successive heating), for example, polyurethane foams and epoxy resins (Burns & Boxall 2018). Most plastics are highly resistant to aging and biological degradation is minimal.

The United States National Oceanographic and Atmospheric Administration (NOAA) defines microplastics as any plastic particle < 5 mm in dimension (Rochman et al. 2019). There is some debate about the lower size limit for microplastics, and nano-sized plastics (< 0.1 mm) are often included in this definition. To address this issue over current sampling and processing practices, a recommendation has been made to report microplastic data in three size classes: 1 ≤ 100µm; 100µm ≤ 350 µm and from 350 µm to ≤ 5mm (Frias & Nash 2019). Overall, the size definition of microplastics remains a source of debate amongst the scientific community (Rochman et al. 2019). Relatively few studies have directly assessed microplastics in nature at or below the 10-50 µm size range because this size range typically falls below the limit of resolution for most of the readily available analysis equipment. However, researchers are continuously expanding their analytical techniques to detect and identify ever smaller microplastics (Rochman et al. 2019). The presence and risks of (nano) plastic have been difficult to ascertain as there are technical challenges for isolating and quantifying them. However, there is a consensus that they can be ingested by organisms at the base of the food chain and pose a risk to the environment and human health (da Costa et al. 2016).

Microplastics come in many shapes and colours and can be a source of contaminants from the chemical additives incorporated into plastic materials during manufacturing processes. They also act as substrate that can directly accumulate pollutants from the environment. The shape of a microplastic particle is often used to assign it to a common category, which helps inform the source. Generally, researchers use between 4 and 7 different categories defined by shape or morphology including fibre, fibre bundle, fragment, sphere (or bead), pellet, film, and foam (Rochman et al. 2019). Fibres and fibre bundles tend to shed from clothing, upholstery, or carpet; pellets, or plastic nurdles, are generally associated with pre-plastic feedstock; spheres may be microbeads from personal care products or industrial scrubbers; and foam often comes from expanded polystyrene foam products such as insulation, construction materials, or food packaging (Rochman et al. 2019).

2.2. Sources

The exceptional properties of plastics (versatility, durability, strength, lightness and transparency) make them 'unique material' for applications in industry, construction, medicine and food safety (Guzzetti et al. 2018). There is a need to distinguish between primary and secondary microplastics and their respective sources. Primary microplastics, including pellets, granules and microbeads, are produced for specific purposes, while secondary microplastics arise from the fragmentation of larger plastic items during use or once released into the environment (Triebskorn et al. 2019). Plastics become brittle and fragment into smaller pieces through exposure to sunlight, UVB radiation and degradation in the atmosphere and seawater to the point of becoming bioavailable and posing potential risk to exposed organisms (Moore 2008).

Human behaviour patterns are responsible for plastic pollution through discarding plastic and from the use of plastic-enabled products that over time break down and release microplastics. This is a global problem rooted in consumptive human behaviour fuelled by convenience and compounded by often absent or inadequate waste management practices and infrastructure (Burgess & Ho 2017). Sources of microplastic pollution include: single use plastic items (bags, bottles, straws and food packaging), textiles, abrasion of vehicle tyres, general waste, products containing microplastics, and equipment / products used in fisheries, agriculture, and industry (Rochman et al. 2019).

Microplastics can be found worldwide in the water and sediment phases of marine and freshwater ecosystems even in the most remote areas of the world, including the deep sea, the Arctic, mountain lakes and in atmospheric deposition. Continental plastic litter enters the ocean largely through storm-water runoff into riverine systems, is dumped on shorelines during recreational activities or directly discharged at sea from ships (Walker et al. 2019). While a significant proportion of microplastics entering wastewater treatment plants (WWTPs) are concentrated and retained within sewage sludge and biosolids, most WWTP technology does not fully remove microplastics. Over 5% of microplastics, in the form of microfibers, remain in the effluent process stream to be subsequently released into the environment via the discharge of treated effluent into water, by effluent irrigation to land, or land application of sewage sludge / biosolids (Keswani et al. 2016; Mason et al. 2016; Nizzetto et al. 2016; Mahon et al. 2017).

2.2.1. Land

The amount of microplastic in terrestrial environments is currently estimated to be equal or greater than the amount in the world's oceans and it is continuing to increase. In one study the amount of plastic residues within soil in an industrial area ranged from 0.03 to 6.7% of the mass of soil (Bläsing & Amelung 2018). Several sources of plastic pollution are associated with a range of land use practices within terrestrial environments (Windsor et al. 2019). Agricultural runoff may incorporate microplastics produced from the degradation of greenhouse films, plastic mulch, irrigation systems, and planters (Koelmans et al. 2017). Urban land use and associated activities also provide several sources of plastic pollution. In particular, loss during waste collection and disposal, industrial spillage and release from landfills provide significant sources of plastic to land (Windsor et al. 2019). For instance, plastic comprised at least 10% of the mass of municipal solid waste in 58% (61 out of 105) of countries contributing data in 2005 (Jambeck et al. 2015).

2.2.2. Fresh water

The major microplastic sources to freshwater ecosystems include land-based plastic litter carried by wind, deliberate dumping, stormwater discharges from urban areas, roadway drainage systems, agricultural runoff, and WWTP effluent discharges. Macroplastic material entering freshwater ecosystems by these same means is eroded and fragmented to microplastics by exposure to sunlight and wind, and abrasion by sediments and water flow (Triebskorn et al. 2019). Current evidence strongly suggests that rivers contain some of the highest concentrations of plastic and are hotspots of plastic pollution. River systems are pivotal conduits for plastic transport within terrestrial, floodplain, riparian, benthic and transitional ecosystems to which they connect (Windsor et al. 2019). Evidence suggests that freshwater systems share similarities to marine systems in the types of processes that transport microplastics (e.g., surface currents); the prevalence of microplastics (e.g., numerically abundant and ubiquitous); the approaches used for sampling, detection, identification and quantification (e.g. density separation, filtration, sieving and infrared spectroscopy); and the potential impacts (e.g. physical damage to organisms that ingest them, chemical transfer of toxicants) (Eerkes-Medrano et al. 2015). In comparison to the marine environment, relatively few studies have investigated the risk presented by microplastics in freshwater ecosystems; the laboratory assessments completed to date have typically used high concentrations of microplastics that are not representative of environmentally realistic concentrations, and only two studies observed adverse effects (Triebskorn et al. 2019).

2.2.3. Marine

In sea water, the plastic polymers commonly present as microplastics are polypropylene (PP), polyethylene (PE), polystyrene (PS), polyvinylchloride (PVC) and polyethylene terephthalate (PET) (Guzzetti et al. 2018).

It is well documented that microplastics are abundant and widespread in the marine environment (Botterell et al. 2019). Worldwide data on solid waste, population density and economic status have been combined to estimate that 275 million metric tonnes of plastic waste was generated in 192 coastal countries in 2010, with 4.8 to 12.7 million metric tons entering the ocean (Jambeck et al. 2015; Burgess & Ho 2017). The main human activities linked to the release of microplastics into the marine environment are aquaculture, fishing, tourism, the food and consumer goods packaging industries, industrial and domestic wastewater systems and plastic litter (Guzzetti et al. 2018). Key receptor species negatively impacted by microplastics include several zooplankton taxa that readily ingest microplastics due to their small size, particularly benthic organisms exposed to high densities of microplastics concentrated in sediment (Botterell et al. 2019). Most organism impact studies have been conducted under controlled laboratory conditions using concentrations of microplastics that are not representative of those prevalent in the marine environment (Botterell et al. 2019). Consequently, it is currently very difficult to assess the risk microplastics may present to biota in natural marine ecosystems.

2.2.4. Microplastics in New Zealand

There is limited information on the quantity and fate of microplastics in the New Zealand environment. However, the use of plastic, recycling and management of waste, together with the quantity of plastic waste and litter produced per capita in New Zealand, are similar to anywhere else in the world. We can therefore expect the quantity, distribution, and impacts of microplastics in New Zealand's environment are likely to be comparable to those observed in other developed countries.

The limited studies of microplastics completed to date in New Zealand have demonstrated the concentration of microplastics in exposed coastal beaches is significantly greater than those in harbour and estuarine environments, suggesting coastal beaches are exposed to microplastics from coastal transport (Clunies-Ross et al. 2016).

The concentration of microplastics in urban streams in Auckland is similar to that within large rivers in Europe and the United States (Dikareva & Simon 2019), suggesting that local-scale factors may be more important than catchment-scale processes in determining microplastic pollution in small urban streams (Dikareva & Simon 2019).

Currently there have been no studies investigating the prevalence and types of microplastics in larger rivers, lakes or ponds, soil, or groundwater in New Zealand.

3. RISK OF MICROPLASTICS

In recent years, plastic pollution has become an issue of environmental concern that has intensively been discussed in the scientific literature and public media (Triebskorn et al. 2019). A similar trend has occurred in New Zealand and this issue is increasingly recognised within our communities. Research on microplastics and their potential risk to ecosystems and humans is complex and many knowledge gaps remain. Some scientists are concerned that the environmental risks from some types of microplastics are exaggerated. For example, the ban on microbeads introduced into many countries including New Zealand may lead to negligible risk reduction as the dominant type of microplastic debris discharged to the environment from wastewater treatment plant effluents are polyester fibres and fragments (Burton 2017). In view of the limited data currently available on the distribution and fate of microplastics in the New Zealand environment, we recommend a precautionary approach is adopted until the significant knowledge gaps are addressed and more robust risk assessments can be made.

It has been suggested that the process of characterising microplastic risk must be based on an analysis of ‘true’ risk incorporating realistic laboratory exposure scenarios based on environmentally relevant exposure and concentrations, followed by field-based evaluations (Burton 2017). Additive or even synergistic effects of microplastics may occur in already stressed ecosystems impacted by excess nutrients, low dissolved oxygen, solids from erosion, pathogens, altered flows, degraded habitats, temperature, and loss of shading. It has been suggested that microplastics may represent a relatively minor risk to ecosystems compared to other major stressors (Burton 2017). There is a call for the science on microplastics to move away from talking in terms of ‘potential’ risks, to encompass ‘a more rigorous and mature risk assessment of plastic debris’ (Koelmans et al. 2017).

The level of uncertainty, knowledge gaps, and the nature of the risks as latent and cumulative mean that any analysis of ‘realistic’, ‘true’ or ‘actual risk’ of microplastics being called for in the literature should be truly interdisciplinary and include robust input from different academic, disciplinary and community knowledge perspectives. It is long established in the social science studies of science, risk, and decision-making that robust risk assessment and risk management approaches ought to include social and political deliberation in addition to biophysical assessments (Kasperson & Kasperson 1996; Nowotny et al. 2003).

Importantly, risk assessments and acceptable levels of risk need to be debated from diverse perspectives as risk can mean different things in different contexts. For example, many expert weightings of risk are informed by exposure guidelines and toxicological standards that are based on western rather than indigenous customary practices around food gathering and consumption. This is particularly relevant for the New Zealand context. Considering different disciplines and sets of expertise is important in formulating assessments and judgements about risk. Where uncertainties exist, it is important for science and policy to have a normative and ethical orientation to acknowledge that risk is subjective rather than absolute. The issue of microplastics has inherent high level of complexity and uncertainty referred as a 'wicked problem'[1] (Brown et al. 2010). As such, wider engagement in a risk assessment process enables different contextual connections to be made, leading to more robust, scalable and multi-pronged interventions to achieve meaningful change, leading to risk reduction.

There are also potential financial and economic risks to consider. The presence of microplastic contamination in the environment could threaten both ecosystems and the economic services they support. This is particularly relevant to New Zealand where primary export industries rely upon terrestrial and aquatic environments that need to be largely free of contaminants to produce high quality food.

3.1. Environmental health risk

The growing amount of interest among the general public, researchers and media has caused plastic debris to be perceived as a major threat to environment and human health. However, many knowledge gaps need to be addressed before the environmental and human health risks of plastics can be fully assessed and ranked against other emerging environmental issues (Koelmans et al. 2017). It is suggested that microplastics can induce physical and chemical toxicity to exposed organisms. These can result in physical injuries, inducing inflammation and stress, or it can result in a blockage of the gastrointestinal tract and a subsequent reduced energy intake or respiration (Guzzetti et al. 2018). The microplastic concentrations detected in the environment are typically orders of magnitude lower than those reported to affect endpoints such as biochemistry, feeding, reproduction, growth, tissue inflammation and mortality in organisms (Burns & Boxall 2018). Consequently, there is currently limited evidence to suggest that microplastics are causing significant adverse impacts, or, that they increase the uptake of hydrophobic organic compounds into organisms (Burns & Boxall 2018).

Although plastic is often described as an inert material because of its chemically stable polymeric structure, every piece of plastic contains a complex chemical cocktail of monomers, oligomers, and other chemical additives. Plastic materials come from a multitude of sources, comprise different sizes, shapes, thickness, density, colours, and types of material. Chemical additives are incorporated into the polymers during production, sometimes accounting for a large proportion of the overall weight (e.g., phthalates, which are used to alter the properties of plastics, can comprise up to 50% of a PVC product's total weight). There are several categories of additives, including

[1] A problem that is difficult to solve because of incomplete, contradictory and changing requirements that are often difficult to recognise.

antioxidants, plasticisers, colorants, reinforcements or fillers, flame retardants, and UV stabilisers (Rochman et al. 2019). The potential bioavailability of compounds added to plastics at the time of manufacture, as well as those adsorbed from the environment are complex issues that merit more widespread investigation (Moore 2008). The hypothesis that microplastics are vectors for hydrophobic organic chemicals that increase their bioavailability to aquatic organisms and ultimately humans is a topic that has been both supported and challenged in research and review papers.

It is undeniable that plastic residue and microplastics adsorb hydrophobic organic chemicals and metals from the environment and can accumulate concentrations many times higher than that of natural organic particulate matter. Although the relative role of microplastics as hydrophobic, organic-chemical vectors to organisms is generally considered minor in comparison to that of natural exposure pathways (such as water, food, and natural particulate matter), it is important to emphasise that microplastic concentrations and environmental conditions change over time, and spatio-temporal hotspots of microplastics do (and will) occur. However, there is little evidence that microplastics play a major role in the bioaccumulation of persistent organic chemicals by biota when compared to their total dietary and environmental exposure (Lohmann 2017). Regardless, the transfer of hydrophobic organic chemicals from microplastics into biota needs to be comprehensively investigated to better understand the effects of weathering, sorption and desorption processes between different polymers under varying conditions (Hartmann et al. 2017).

Microplastics could present a pathway for organisms to be exposed to chemical additives that otherwise would not be easily transferred into the environment. It has been suggested that research should focus on the release of phenolic additive-derived chemicals (i.e. alkylphenols, bisphenol A, UV stabilisers and anti-oxidants) from microplastics to the food web but there are no data to date demonstrating the ingestion of microplastics presents a pathway for the uptake of these compounds by biota (Lohmann 2017).

Some caution is warranted when interpreting the significance of the outcome of earlier studies assessing the risk of chemical contaminants in microplastics. The wide range of experimental conditions, test concentrations and test organisms used in these investigations is likely to either over or under-estimate the resulting exposure risk. Significantly, concentrations of microplastics and contaminants used in many of these studies are orders of magnitude higher than those typically found in natural ecosystems where the concentrations of natural particles, algae and invertebrates that organisms are feeding on are greater than those of microplastics and therefore preferentially ingested by biota (Burton 2017). Importantly, there is growing demand from scientists to use standardised methods for collecting, quantifying, and characterising microplastics, combined with common species of biota and test conditions so the results obtained from different studies can be compared (Burton 2017).

3.1.1. Biosecurity risk

Microplastics are a suspected biosecurity risk, acting as mobile substrates or microrafts for the spread of pathogens and invasive species within environments they would otherwise be absent from (Gregory 2009; Eckert et al. 2018; Lamb et al. 2018). There are several known sources for the accumulation and spread of plastic litter and associated organisms. It has also been hypothesised that microplastics may provide a vector for rafting sewage-associated pathogenic microbes that survive wastewater treatment in WWTPs that survive wastewater treatment, thereby providing a vector for the pathogens and / or antibiotic resistant microbes into the environment via the discharge of treated effluent (Keswani et al. 2016; Eckert et al. 2018). Finally, plastic at sea may transport alien species over long distances or act as substratum for mobile and fixed organisms, providing a support to colonisation (Casabianca et al. 2019).

3.2. Human health risk

For ecosystems and biota, the evidence so far is the ecological risks of microplastics are low, apart from locations where microplastics are likely to be concentrated. For plastics of sizes below 5 mm, there are some locations in coastal waters and sediments where ecological risks might currently (SAPEA 2019).

Likewise, the potential human health effects of microplastics are unknown (Wright & Kelly 2017). The risk of microplastic exposure to humans could occur via diet (food and water) or inhalation as evidenced by the observations of plastic microfibres in lung tissue biopsy samples (Wright & Kelly 2017). A recent Science Advice for Policy by European Academies report, based on an interdisciplinary analysis by independent scientists, highlights that occupational exposure of workers to microplastics can lead to granulomatous lesions, causing respiratory irritation, functional abnormalities and other conditions such as flock worker's lung in humans (SAPEA 2019). The chemical additives in microplastics can have additional (and difficult to assess) human health effects, such as reproductive toxicity and carcinogenicity but the risk is probably small at present (SAPEA 2019). Overall, while there is strong evidence of the impacts of microplastics in animal models under laboratory conditions, it is not known if this translates to an actual risk to humans. There is limited information on the potential transfer of microplastics and associated contaminants from seafood to humans and the implications for human health. A significant knowledge gap in this respect is the absence of bioaccumulation factors for microplastics in commonly consumed types of seafood which is a prerequisite to establishing the potential human health impacts of microplastics in seafood (Carbery et al. 2018).

4. MANAGING THE RISK OF MICROPLASTICS

There is no single solution to a global problem that is rooted in consumptive human behaviour, fuelled by convenience and compounded by often absent or inadequate waste management practices and infrastructures (Burgess & Ho 2017). One potential solution is the development of alternatives to petrochemical-based plastics, e.g. using plant-based materials to produce truly biodegradable plastics. However, the misconception that these so-called biodegradable plastics are viable alternatives to conventional plastics needs to be acknowledged (Burgess & Ho 2017).

While some of the risks associated with microplastics have been investigated, many remain unaddressed as scientists, politicians, and the wider society continue to debate the magnitude of the problem that plastic waste and microplastics may represent (Burgess & Ho 2017). Burgess and Ho (2017) facilitated a specialists' debate regarding the risks of microplastics in aquatic environments by bringing together 7 representatives and viewpoints from industry, government, academia, and a nongovernmental organisation. These specialists agreed a coordinated approach was a prerequisite to resolving this complex issue. There was a strong consensus that some caution is warranted when interpreting the results and conclusions from many of the published studies on the impact and risks of microplastics in the environment. It is critical that effect and monitoring studies use robust and validated experimental designs in order to identify the materials, activities and practices representing the highest contribution to the problem (Burns & Boxall 2018). As such, the experimental design, and analytical methods that have been employed in studies assessing the impact and risk of microplastics in the environment must be carefully reviewed before considering the significance of the stated risk.

Although the evidence of harm from microplastics remains to be confirmed, efforts to reduce the release of plastic material into the environment should remain a priority. The view of non-government organisations is that 'we know enough to act' illustrating the rising public sentiment and concern that the issue of plastic pollution needs to be more proactively managed (World Economic Forum 2016).

Technical solutions are emphasised. For example, microfibres are among the most common types of microplastics found in environmental samples, and the production, use, and washing of synthetic textiles, including clothing, is recognised to be a significant source. As such, filters on washing machines may be a simple solution to prevent the release of microfibres into WWTPs and subsequently into the environment. The increasing adoption of plastic-based materials used in the construction industry represents another potentially significant source for microplastics, particularly as these materials weather and age. In addition, tyre wear particles are known to be the source of a large fraction of microplastics within stormwater, urban and roading network runoff entering the environment. Interception and capture methods including bioretention cells, rain gardens and sand filters have the potential to reduce the amount of microplastics entering urban catchments from these sources (Rochman et al. 2019).

It is recognised that community awareness and behaviour change are part of the suite of required solutions. The plastic issue is similar to other environmental issues from the science literature in that it requires increased emphasis on consumer behaviour, behaviour change and consumer choice to better manage human impacts on the environment (Pahl & Wyles 2017). Recent New Zealand consumer research suggests that 72% of New Zealanders are increasingly aware and concerned about the build-up of plastics waste in the environment (Colmar Brunton 2018).

One way to reduce plastic pollution in the environment is to minimise the amount of single-use plastic used in our daily lives. However, relying on consumer behaviour change approaches is problematic for many reasons, including that plastics are ubiquitous and embedded in all aspects of our daily life—in food production, transport, communications, hygiene, medical and personal use. While consumer choice can contribute to sustainable change, avoiding plastics requires a significant change in regulation, infrastructure, technologies and social practices in order to influence household consumption and patterns of use. Consumer pressure has been effective in encouraging businesses to consider more sustainable alternatives to disposable plastic products including reducing the use of plastic bags, straws and packaging, but far more attention, research and effort is needed in the re-design of viable socio-technical alternatives to plastics if we are to achieve meaningful sustainable change.

While small choices and individual household actions can add up, we lack the tools to measure, consolidate and prove this. There are also significant socio-economic factors—many households are time poor, cash poor, transport poor, geographically isolated, etc. and therefore have very limited options available to participate in exercising a ‘choice’ to reduce plastics in everyday life. The most effective way to reduce plastics pollution is upstream design / redesign to stop producing plastics in the first place, and to invest in finding viable alternatives in manufacturing, production and distribution. This approach requires structural change, including regulation, industry investment in change, and investment in science, innovation, disruptive technologies etc.

Consumer lobbying of industry and politicians is arguably a far more effective pathway for building sustainable change, especially given increased access and participation in social media technologies, and the speed, influence and power of social networking (Hindmarsh & Calibeo 2016). The value of consumer action lies in social networking for organised and tactical lobbying for political, regulative and industry change. Consumer choice and voluntary consumer action offers fairly ineffective downstream response, unless combined with regulatory and policy levers.

It is important to reduce the entry of additional plastic waste into the environment through better litter collection and recycling capacity. These initiatives could be effective through the combined actions of the public, industry, scientists and policy and possibly increased funding for cleaning our oceans (Rochman et al. 2019). There is recognition that voluntary consumer initiatives and citizen science-oriented beach clean ups are downstream interventions that are not very effective in terms of reducing risks and impacts (Burgess & Ho 2017). It is important to note that consumer behaviour change is only a very small aspect of the multi-pronged solutions required to address this wicked problem. Some authors have stated that more respect for the environment and its ecosystems by industry and the general public is needed before this problem can be resolved (Guzzetti et al. 2018).

The IPBES 2019 global assessment synthesis of 15,000 publications related to biodiversity decline, notes that changes in consumption make limited contribution to actual reductions in waste (United Nations 2019). This comprehensive global study notes the importance of multi-actor governance interventions, leverage points, strategic policy mixes, scaling and coordination of effort. Other studies emphasise that effective risk management strategies ought to focus on regulation, politics and industry practice, circular economies, green chemistry and 'de-materialisation' to get plastics out of the economy (World Economic Forum 2016).

A risk assessment framework for plastic debris of all sizes and in all habitats has been proposed (Koelmans et al. 2017). This framework aligns with other global environmental studies (IPBES 2019; World Economic Forum 2016) suggesting that widening the boundaries of inquiry from microplastics to encompass addressing the impacts of macro plastics and waste in the environment would be prudent for risk management frameworks.

4.1. International strategies to manage microplastics

Numerous policy and regulatory developments have been implemented around the globe to reduce the use and emissions of microplastics. Perhaps the most publicised are the ban of microbeads in all wash-off cosmetic products including the United States' Microbead Free Water Act of 2015 and the United Kingdom's Environmental Protection (Microbeads; England) Regulations 2017 (Burns & Boxall 2018). The bans were followed up by other countries including Canada and New Zealand (Rochman et al. 2019).

A ban on single-use plastics by 2021 in Canada will consider a wider range of plastic products including not only plastic bags, but straws, cutlery, plates and stir sticks[2].

[2] https://www.nationalgeographic.com/environment/2019/06/canada-single-use-plastics-ban-2021/

The objective of these bans is to remove a major plastic pollution source by reducing litter.

The development of governance and mitigation strategies to manage the issue of microplastics is very challenging due to the high level of complexity of this issue (Rochman et al. 2019). Despite these limitations, there are policy initiatives for reducing marine litter aiming at: 1) understanding presence and impacts, and 2) preventing further inputs or reducing total amounts in the environment (Eerkes-Medrano et al. 2015). Examples of efforts to manage marine litter include the US Interagency Marine Debris Coordinating Committee (IMDCC), which supports the US national / international marine debris activities, and 'recommends research priorities, monitoring techniques, educational programs, and regulatory action'. The European Commission's Marine Strategy Framework Directive (the Directive) has designated a Technical Subgroup on Marine Litter to provide 'scientific and technical background for the implementation of Directive requirements', which include identification of research needs, development of monitoring protocols, preventing litter inputs and reducing litter in the marine environment. The Directive's 'litter' designation includes microplastics and acknowledges a limitation in 'knowledge of the accumulation, sources, sinks … environmental impacts … temporal and spatial patterns and potential physical and chemical impacts' of microplastics (Eerkes-Medrano et al. 2015).

Although the risks from microplastics are still unclear, there is a need to focus on solutions, such as proper regulations on plastic production, waste management practices, plastic recycling schemes, and politicians encouraging a change of attitude by society (Burgess & Ho 2017). There is more public, policy and management interest for marine than freshwater ecosystems due to greater knowledge and publicity of the extent and impacts of microplastics in the marine environment, but overall more effort is needed to address and manage the issues of plastic pollution (Eerkes-Medrano et al. 2015).

There is an increasing number of initiatives lead by NGOs to address the issue of microplastics in the environment. For instance, a group of international scientists wanting to prevent plastic pollution have formed the Plastic Pollution Emissions Working Group (www.plasticpeg.org). International NGOs raising awareness of the global impact of plastic and microplastics include Algalita and 5 Gyres. In New Zealand, Sustainable Coastlines are actively raising awareness about plastic pollution, encouraging debate of this issue, and identifying mitigation and reduction solutions. Improving waste management infrastructure in developing countries is paramount and will require substantial resources and time. While such infrastructure is being developed, industrialised countries can take immediate action by reducing waste and curbing the growth of single-use plastics (Jambeck et al. 2015).

5. THE NEW ZEALAND SITUATION

5.1. Government initiatives

The reason for the microbead ban by the New Zealand government is to *prevent plastic microbeads, which are non-biodegradable, entering our marine environment. They can harm both marine life and life higher on the food chain including humans*[3]. Furthermore, New Zealand has banned single-use plastic bags, although many retailers had already phased them out[4]. In addition to the bans on microbeads and single-use plastic bags, the government is also involved in a range of initiatives to reduce the amount of plastic entering the environment in New Zealand. The Office of the Prime Minister's Chief Science Advisor established a panel to investigate options to reduce the impact of plastic: Rethinking Plastics in Aotearoa, New Zealand (https://www.pmcsa.ac.nz/our-projects/plastics/). New Zealand is a signatory to the United Nations-led CleanSeas campaign to rid our oceans of plastic. New Zealand also signed the New Plastics Economy Global Commitment, an initiative led by the Ellen MacArthur Foundation, in collaboration with the United Nations Environment Programme.

5.2. Resources and expertise

Research capability and expertise in the field of microplastics is growing in New Zealand. One important requirement is the development of science capability to measure and characterise microplastic particles based on their structure and chemical composition and assess their impact and risk. Table 1 summarises the current organisations and equipment they employ to characterise plastic and microplastics in New Zealand.

5.3. Current microplastics research initiatives and funded projects

There has been a noticeable increase in microplastic-related research in New Zealand and the main research projects currently underway are summarised in Table 2. The ESR-led microplastics MBIE Endeavour Aotearoa Impacts & Mitigation of Microplastics is the single largest project and summaries of the research programme objectives, and critical steps are provided in Appendix 1.

[3] https://www.mfe.govt.nz/waste/waste-strategy-and-legislation/plastic-microbeads-ban
[4] https://www.beehive.govt.nz/release/mandatory-phase-out-single-use-plastic-bags-confirmed

Table 1. New Zealand-based capability to measure and characterise microplastics.

Organisations	Capability
Institute of Environmental Science and Research (ESR), Scion Research and the University of Canterbury	ATR-FTIR and FTIR-microscope instruments for the identification and quantitation of microplastics SEM and TEM instruments with confocal capabilities for physical and chemical analysis of microplastics
University of Auckland	Stereomicroscopes with digital camera systems for visual identification, counting and size measurement of microplastics
Scion Research	Solid-state NMR and pyrolysis-GC instruments for polymer characterisation, laboratory facilities to accelerate polymer weathering, and purpose-built state-of–the-art biodegradation facilities to assess the fate of different types of polymer, and polymer-microbe interactions under environmental conditions

Table 2. New Zealand research projects on microplastics.

Lead	Project
Florian Graichen, Scion Research	National marine sediment survey- MfE Waste Minimisation Fund
Sally Gaw (Canterbury), Andrew Pearson (MPI)	Assessment of microplastics in mussels and an MSc project assessing microplastics in WWTP influent and effluent
Grant Northcott	Review on biodegradable plastics and chemical additives in plastic for The Parliamentary Commissioner for the Environment
Francine Harland- NZ Royal Society	Report on the impacts of plastics in the environment for the general public
Olga Pantos, ESR	Project with Ngāi Tahu on the presence of microplastics in mahinga kai
Amanda Valois, NIWA	Microplastics from urban environments entering an estuary (Porirua Harbour). Citizen science theme, MBIE Smart Idea
Julie Hope, University of Auckland	The role of microalgae and ocean sediments in the accumulation of microplastics by biota. Royal Society Marsden Fast-Start
Olga Pantos (ESR), Grant Northcott	Impacts of microplastics on New Zealand's bioheritage systems, environments and ecoservices. MBIE Endeavour 5-year Aotearoa Impacts & Mitigation of Microplastics programme

6. CONCLUSIONS AND RECOMMENDATIONS

The risks microplastics pose to ecosystem and human health are not fully characterised and many research and knowledge gaps remain. Research on microplastics is a very new field and there is limited information about their risks, particularly in New Zealand. The main risks are likely due to the multiple chemical additives used in plastics. Therefore, microplastics may represent a major source of these chemical additives into the environment and to exposed biota. Findings so far suggest that microplastics are likely to pose risks at hot spots where concentrations will be highest and in combination with other stressors. In view of the significant knowledge gaps, we recommend a precautionary approach until the risks are better characterised. As such, regional councils need to keep abreast of the latest developments through close communication with the main research groups in New Zealand. The **research gaps** identified in this review include:

- assessment of the prevalence and types of microplastics in soil and larger freshwater catchments including rivers and lakes impacted by human activity
- a similar assessment for groundwater, particularly as there is a trend in New Zealand to remove WWTP discharges from water and instead dispose on land
- as previous research has focused on marine environments, there is a need to better understand the risk microplastics represent to estuarine, coastal, freshwater and terrestrial (soil) environments
- assessment of the potential impact and risk of microplastics on taonga species in New Zealand, for example native fish species; tuna, whitebait etc.
- characterisation of human exposure to microplastics via recreational and customary harvest to assess whether consumers of wild foods; mana whenua may particularly be exposed to an increased dietary loading compared to the general population.

Recommendations that can assist regional councils to address issues related to microplastics within their regions include:

1. Keeping up to date with the progress of the microplastics research projects and particularly the ESR-led Aotearoa Impacts & Mitigation of Microplastics project, which is a national 5-year MBIE funded research programme. Other options include invitations to project leaders and key scientists to provide overviews at relevant Special Interest Group meetings; asking for focus sessions / workshops at scientific national conferences.
2. Explore opportunities to collaborate and increase participation in the various research projects through providing samples and other complementary initiatives.
3. Risk management strategies for microplastics should look at consumer behaviour as part of multi-level collaborative planning for the design of effective combined actions to protect environmental and human health. In working towards this aim,

the inclusion of diverse viewpoints within local risk assessment processes will support more effective and comprehensive risk management approaches.

4. Align with the Tiriti o Waitangi process and mana whenua as key partners in environmental and resource management. Regional councils should continue to work closely with mana whenua in risk assessment to reflect actual risks in context of cultural values and practices, and in the design of co-management strategies and coordinated national policy and industry initiatives to reduce the impacts of human waste, land use and production practices on the receiving environment.

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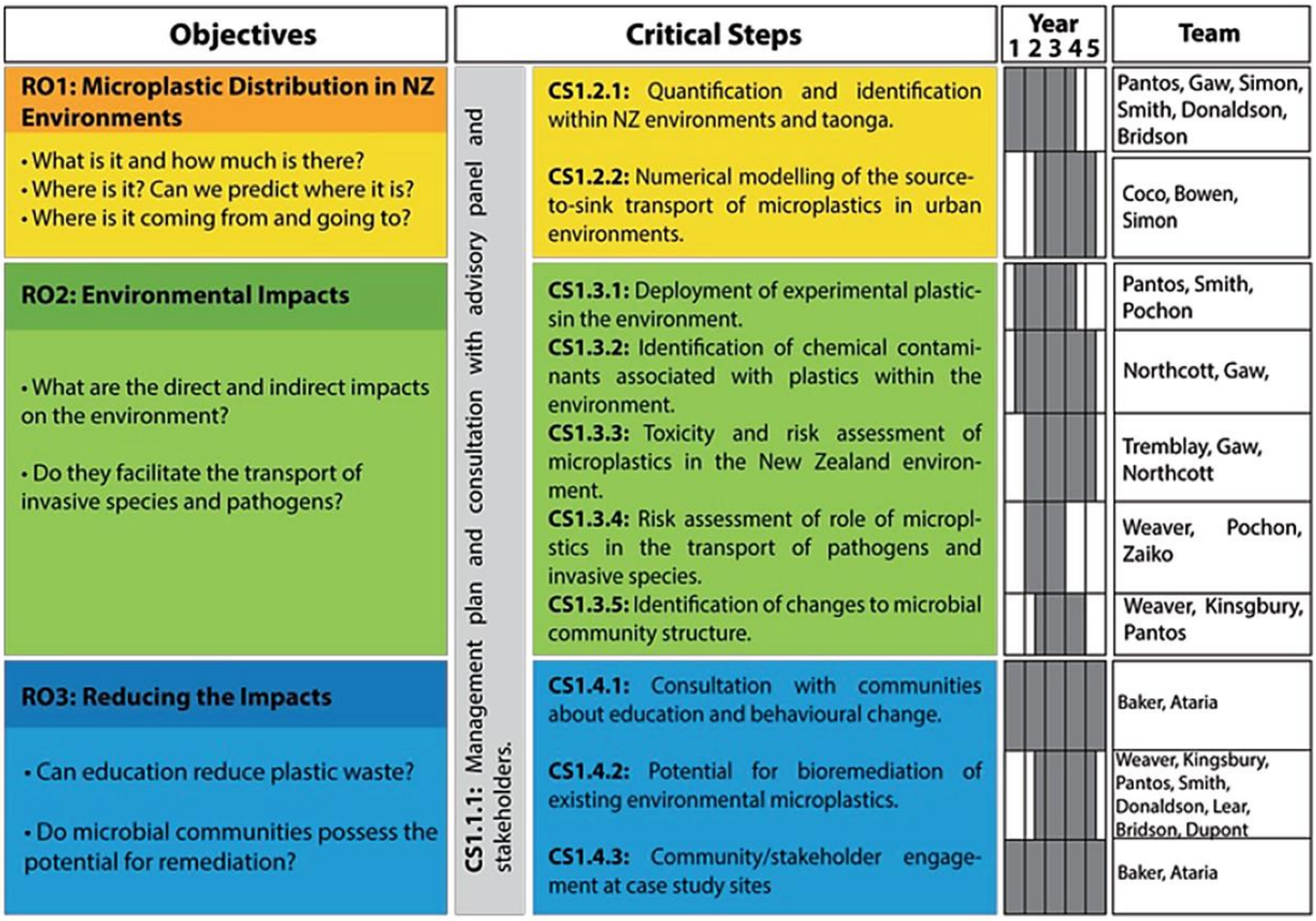
8. APPENDIX

Appendix 1. Research and engagement programme: a schematic representation of the ESR-led MBIE Endeavour Aotearoa Impacts & Mitigation of Microplastics project showing the main objectives and critical steps and the scientists involved.



Objectives		Critical Steps	Year 1 2 3 4 5	Team
RO1: Microplastic Distribution in NZ Environments • What is it and how much is there? • Where is it? Can we predict where it is? • Where is it coming from and going to?	**CS1.1.1:** Management plan and consultation with advisory panel and stakeholders.	**CS1.2.1:** Quantification and identification within NZ environments and taonga.		Pantos, Gaw, Simon, Smith, Donaldson, Bridson
		CS1.2.2: Numerical modelling of the source-to-sink transport of microplastics in urban environments.		Coco, Bowen, Simon
RO2: Environmental Impacts • What are the direct and indirect impacts on the environment? • Do they facilitate the transport of invasive species and pathogens?		**CS1.3.1:** Deployment of experimental plastics in the environment.		Pantos, Smith, Pochon
		CS1.3.2: Identification of chemical contaminants associated with plastics within the environment.		Northcott, Gaw,
		CS1.3.3: Toxicity and risk assessment of microplastics in the New Zealand environment.		Tremblay, Gaw, Northcott
		CS1.3.4: Risk assessment of role of microplstics in the transport of pathogens and invasive species.		Weaver, Pochon, Zaiko
		CS1.3.5: Identification of changes to microbial community structure.		Weaver, Kinsgbury, Pantos
RO3: Reducing the Impacts • Can education reduce plastic waste? • Do microbial communities possess the potential for remediation?		**CS1.4.1:** Consultation with communities about education and behavioural change.		Baker, Ataria
		CS1.4.2: Potential for bioremediation of existing environmental microplastics.		Weaver, Kingsbury, Pantos, Smith, Donaldson, Lear, Bridson, Dupont
		CS1.4.3: Community/stakeholder engagement at case study sites		Baker, Ataria