Microplastics in the marine environment: Sediment contaminant and bioaccumulation rates in bivalves within the Bay of Plenty

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Abstract

Microplastic pollution is recognised as a significant anthropogenic issue in coastal ecosystems around the world. The accumulation of microplastics in coastal environments causes both direct and indirect effects on these already vulnerable ecosystems. Limited information was available of the scale of microplastic pollution across New Zealand, including the Bay of Plenty. To enable a greater understanding of microplastic accumulation in sediment and bioaccumulation in bivalves sampling within the Bay of Plenty area was conducted.

The presence of microplastic particles was investigated from sediment and shellfish samples collected across the Bay of Plenty, from Waihī Beach in the West, to Ōpōtiki in the East. Three species of shellfish were collected that differed in their functional feeding modes (filter feeder vs deposit feeder): tuangi (cockle: *Austrovenus stuchburyi*), hanikura (wedge shell: *Macomona liliana*), and tuatua (surf clam: *Paphies subtriangulata*). Microplastic particles from sediment and bivalves were separated from the sediment and shellfish samples in the laboratory and identified using visual light stereomicroscopy. Microplastic particles were identified and quantified into three categories: fragments, fibres, and films.

Significant numbers of fibres, as well as some fragments and films were found to be present in the sediment throughout all sampling locations. The highest density of microplastic particles in sediment (up to 11,087.9 per m^2) were observed at sites that were closed to municipal sewage outfalls and populated areas, and the lowest densities were observed at Matakana Island (63 particles per m^2). Sites in Ōhiwa Harbour showed an average of 504.6 particles per m^2 at the high tide zone and 477.6 particles per m^2 at the intertidal zone in the sediment. Ohiwa Harbour showed similar levels of microplastic accumulation in sediment

compared to Tauranga Harbour. However, higher levels of microplastic particles were found in the sediment at open coast sites.

All shellfish sampled had at least one microplastic particle found in their tissues. The highest number of microplastics in shellfish were found in the wedge shell (23 particles), with the least from the cockles (1). Statistical analysis reveal that the deep burrowing deposit feeder (*Macomona liliana*) demonstrated an elevated amount of microplastic particles ingested relative to the shallow burrowing suspension feeding cockle (*Austrovenus stutchburyi*). A notable amount of microplastic particles were also found at all sampling locations for the culturally important tuatua (*Paphies subtriangulata*). However, comparing all three bivalve species, the deposit feeding *M. liliana*, ingested higher amounts than both the *A. stutchburyi* and *P. subtriangulata*, which could be related to their different functional feeding modes in the marine environment. This research provides baseline information to assess the extent of microplastic pollution in sediments and the potential for bioaccumulation in bivalve species with differentiated feeding modes and functional roles in the marine environment.

The problem with microplastics is a global emerging contaminant. Preventing the problem of plastic wastes in New Zealand will require change across all aspects of society, along with policy regulations to mitigate the issue of microplastic pollution.

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Chapter 1

Introduction

1.1 General Introduction

There have been significant rises in plastic pollution within aquatic systems since the 1950's, and it is increasingly becoming a major issue worldwide due to the slow decomposition rates of these materials (Besley et al., 2016; Gregory, 1978; Lots et al., 2017). Due to the impacts humans have on the environment, we have entered a new era called the Anthropocene with plastic pollution considered to exert one of the greatest effects (Brander et al., 2020). Land use around coastal areas are a contributing factor for microplastic pollution to the marine environment (Jang et al. in 2020). Microplastic pollution have been discovered in sediment on seven continents on earth, with significant implications for ecosystem and human health (Yu et al., 2020). Numerous studies have been conducted internationally on microplastic pollution in beach sediment, making it the most extensively studied topic to date for this emerging contaminant (Harris, 2020; Imhof et al., 2013; Korez et al., 2019; You et al., 2020).

Samples were collected and investigated from three locations in South Korea; an urban area, rural location and an aquaculture farm (Jang et al., 2020). Different marine matrices were investigated; sediment, water and biota, and they noted the presence of diverse polymer types across all three matrices sampled in the urban area (Jang et al., 2020). Furthermore, polymer types found at the rural and aquaculture farm were a representation of the associated activities in the areas, thus a significant relationship exists between human activities and microplastic pollution to the marine environment (Jang et al., 2020).

Plastics are polymers that are synthetically manufactured from constituents such as cellulose, coal, natural gas, salt and crude oil through a process called polymerisation (Browne, 2015; Geyer et al., 2017; Lots et al., 2017). Microplastics are small plastic particles (< 5 mm) that persists in the environment (Hidalgo-Ruz et al., 2012; Imhof et al., 2012). Microplastics can be divided into two major groups, including (1) primary microplastics (fragments, fibres and films) that are 5 mm and smaller at the time they enter the environment, for example, nurdles, and (2) secondary microplastics, which are large items entering the environment, for example, plastic water bottles, that break down into smaller particles through weathering and other environmental processes (Besley et al., 2017; Frias & Nash, 2019; Imhof et al., 2013; Lots et al., 2017; Shim et al., 2017). Quantification of microplastic particles in sediment were investigated at Spiekeroog and Kachelotplate, two East Frisian islands, and they discovered fragments and fibres to be the most abundant, with up to 496 particles per 10 gram of sediment at the high tide zone (Liebezeit & Dubaish, 2012).

It is essential to note the sources and transport of microplastic pollution input to the environment to gain insight of the overall extent of the issue. Furthermore, it is important to note the occurrence of microplastic particles in freshwater systems as these systems often serves as an interface between terrestrial systems and the ocean (Dikareva & Simon, 2019). A study on microplastic contamination of riverbeds at 40 sites in the UK found significant numbers and microplastic hotspots throughout the river channel beds with up to 517,000 particles m^{-2} (Hurley et al., 2018). After a flood event it was noted that the microplastic concentration reduced by 70%, with the likelihood of transporting and flushing the microplastic particles to coastal areas (Hurley et al., 2018).

A study was also conducted on the largest rivers in Europe to gain an understanding of different sources and types of microplastic particles entering the riverine system and ultimately ending up in the marine environment (Siegfried et al., 2017). Human activities and point-sources of plastic pollution were modelled as a function of the export of microplastic particles in riverine systems (Siegfried et al., 2017) (Fig. 1). A major source of microplastic input to the environment noted in this study, was derived from sewage around highly populated areas, thus recommendations were made for the improvement in sewage systems and treatment (Siegfried et al., 2017). The Mediterranean Sea encompassed the greatest microplastic particle load recorded in marine studies to date, which demonstrates that microplastic particles are transported from the terrestrial environment to the ocean (Siegfried et al., 2017).

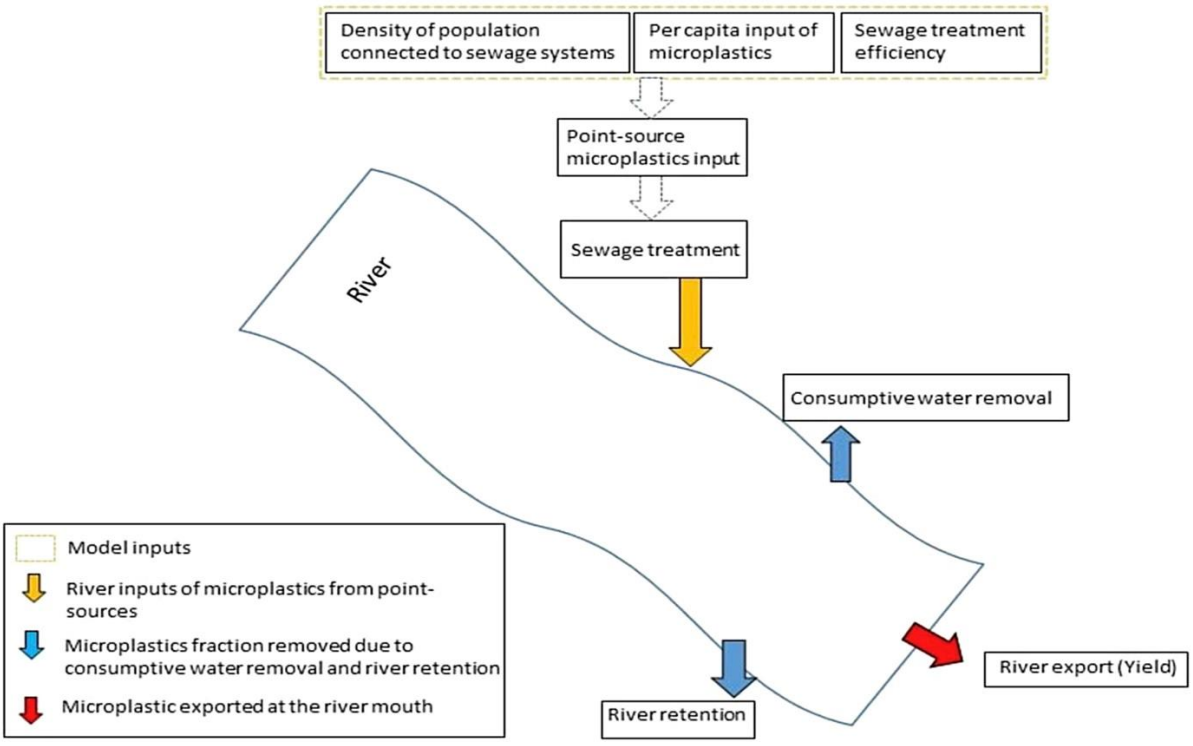

Figure 1. *Diagram of the modelling approach applied by Siegfried et al. in 2017 to explain microplastic export in European river systems.*

Additional pathways and distribution of microplastic pollution based on characteristics of the plastic particles have been identified in a European study (Ballent et al., 2012). The results demonstrated spatial and temporal distribution of microplastic particles based on inherent microplastic properties, such as shape, size and density, combined with extrinsic factors such as ocean water density, benthic sediment structure and flow velocity (Ballent et al., 2012). This provides for a better understanding of the residence time of microplastic particles in the marine environment, as well as the subsequential exposure of marine biota to microplastic pollution.

Microplastics can also function as “toxic rafts” due to their hydrophobic nature, therefore, accumulating toxins and other pollutants as they disseminate through the environment (Masura et al., 2014; Nerland et al., 2014). Microplastic particles that have undergone aging and weathering shows a greater affinity for sorption of pollutants compared to newly introduced particles (Guo & Wang, 2019). Furthermore, the study by Guo & Wang in 2019 indicated higher concentrations of pollutants on microplastic particles in large cities compared to those found in rural areas. A study by Hartmann et al. in 2017 identified several regulating processes influencing the sorption of hydrophobic organic chemicals (HOC) by microplastic particles. Processes contributing to microplastic particles acting as HOC vectors include, polymer type, weathering of the microplastic particle and the planarity of the chemical molecule will determine how near it can move to the microplastic particle’s surface (Hartmann et al., 2017). Furthermore, it is important to investigate the sinking rate of microplastic particles as this would assist in understanding microplastic behaviour in the environment. A laboratory study by Kowalski in 2016 experimented with various polymer types and sizes in fluids with different salinity. They found that sinking velocity were linked to particle density, size, and shape as well as fluid density (Kowalski et al., 2016). These results

could be explanatory for the spatial and temporal occurrence of various polymer types in different aquatic systems and their residence time in the water column (Kowalski et al., 2016). The behaviour, dispersion and persistence of microplastics in the environment are a complex topic due to the various polymer types encompassing microplastics which should be taken into consideration when executing microplastic research (Rochman et al., 2019).

One significant sink for microplastics settling out of the water column is marine sediments. This is also one of the habitats that has been most widely studied (Ballent et al., 2012; Harris, 2020; Silva et al., 2018; You et al., 2020). A review done by Harris in 2020 on microplastic concentrations in various sedimentary environments showed the greatest accumulation in fjords (7000 particles per kg^{-1} dry sediment), 300 particles in estuaries, 200 particles in beach sediment and 200 particles in shallow coastal environments (Harris, 2020). Furthermore, Harris reviewed the relationship between sediment grains and microplastic particles, comparing their properties and similarity in behaviour when dispersing through the environment (Harris, 2020). Harris noted that microplastic particles with hydraulicly comparable physical attributes to sediment particles distribute similarly in the environment, with coarse particles deposited in close proximity to the source (Harris, 2020; Kane & Clare, 2019). However, microplastic particles have a much lower density than sediment grains which would have an effect on the buoyancy of the particles in comparison to sediment grains (Harris, 2020; Kane & Clare, 2019). The lower density microplastic particles will be more buoyant and therefore transported in suspension as opposed to sediment grains being transported in the bedload (Harris, 2020; Kane & Clare, 2019). Open coast beaches are subject to tidal fluctuations, storm events, wind and wave action as well as changes in beach geomorphology which could have an effect on sediment and microplastic transport and deposition on sandy beaches (Harris, 2020). Harris noted a bias, that most sampling sites were

selected based on highly populated areas and sewage outfalls, which would be expected to display an increase in microplastic accumulation within the sediment, as opposed to pristine locations (Harris, 2020). The primary morphotype of plastic particles found in the 80 studies reviewed were microplastic fibres and they predominantly occurred in beach environments (Harris, 2020). Microplastic fibres have greater buoyancy due to their surface area to mass ratio, keeping them suspended in the water column for extended periods enabling deposition elsewhere (Harris, 2020). Furthermore, fragments are likely to settle faster out of suspension and will most likely accumulate in estuarine and mudflat environments (Harris, 2020). Harris concluded that higher accumulation of microplastic particles were present in coastal areas compared to deep sea trenches due to hydraulic energy in these environments (Harris, 2020).

As previously noted, microplastic accumulation are prevalent in a wide range of ecosystems. In Singapore accumulation of microplastic particles were investigated in intertidal mangrove habitats and were present at all the sampling locations (Mohamed Nor & Obbard, 2014). The most prevalent morphotype present were microplastic fibres (Mohamed Nor & Obbard, 2014). They identified the likely source of pollution to be due to chemical weathering of discarded macroplastics in the mangrove forests (Mohamed Nor & Obbard, 2014).

The presence and fate of microplastic accumulation in the New Zealand environment is not well understood with limited studies (Bridson et al., 2020; Clunies-Ross et al., 2016; De Bhowmick et al., 2021). In New Zealand, only a few studies have been conducted to assess the presence of microplastic particles in freshwater systems (Dikareva & Simon, 2019; Mora-Teddy & Matthaei, 2020). A study conducted on small urban streams in Auckland, New Zealand against an urban gradient, demonstrated that microplastics were spatially widespread and present in all the streams and in some areas, present in higher concentrations

than in larger river systems investigated overseas (Dikareva & Simon, 2019). A greater spatial study (Mora-Teddy & Matthaei, 2019) investigated streams in urban clusters of Auckland, Hamilton, Wellington, Christchurch and Dunedin in New Zealand with microplastic particles found in every sample (Mora-Teddy & Matthaei, 2020). Concentrations varied between 0.03 and 44.8 items/m^3, with the majority of sites showing less than 1 item/ m^3 (Mora-Teddy & Matthaei, 2020). These results were comparable to international studies demonstrating similar concentrations and furthermore, highlighting smaller urban streams as major transport vectors of microplastic pollution (Mora-Teddy & Matthaei, 2020).

Two studies have assessed accumulation of microplastics in coastal and estuarine environments in New Zealand. A study by Bridson et al. (2020) launched a large scale investigation of microplastic particle accumulation in sediment around 39 locations across the highly populous city of Auckland, New Zealand (Bridson et al., 2020; De Bhowmick et al., 2021). Bridson et al. (2020), reported an average of 459 plastic particles per m^{-2} or 6 particles per kg^{-1} extrapolated across the sampling localities (Bridson et al., 2020). Primary point-sources of the pollution was identified and included stormwater inputs, wastewater treatment plants, industrialised locations, river mouth openings and recreational activities such as fishing (Bridson et al., 2020). Three primary wastewater treatment plants (Mangere, Rosedale, & Army Bay), as well as some smaller plants, were identified as major contributors to microplastic input to the marine environment in Auckland (Bridson et al., 2020; De Bhowmick et al., 2021). One of the first studies in New Zealand on the accumulation of microplastic particles in sediment was conducted around the Canterbury area (Clunies-Ross et al.,2016). Ten locations were sampled and microplastic accumulation found to be present at eight of the locations with up to 45.4 particles per kg^{-1} extrapolated (Clunies-Ross et al., 2016; De Bhowmick et al., 2021).

A study of the Waitemata Harbour in Auckland confirmed microplastic accumulation found in sediment from similar studies conducted in this area (Hope et al., 2021). Furthermore, no relationship between population density and microplastic accumulation were perceived a factor, however, urbanisation and the use of wastewater treatment plants are ascribed as sources of microplastic input in sediment within the Waitemata Harbour (Hope et al., 2021). Chemical composition of the microplastics found in the Waitemata Harbour were similar to the Bridson et al study in 2020, with polypropylene and polyester identified as the dominant plastic types (Hope et al., 2021). Polyester has a higher density than seawater resulting in faster sinking rates even in highly dynamic environments (Hope et al., 2021). Hope et al. (2020) concluded that sediment grain size influence microplastic-sediment relationships, with ecologically important ecosystems in muddy estuaries being at the most risk, due to the change microplastics exert on habitat functionality.

In recent years, the effects of macroplastics on marine biota have become evident and pose significant threats such as blockage of their digestive tracts and drowning due to entanglement (Laist, 1987; Worm et al., 2017). However, the greater extent of effects of microplastic particles on biota as an emerging contaminant is relatively novel and not well understood. Microplastics are ubiquitous in the environment, are frequently ingested by organisms, and may potentially cause harm. Microplastic particles bioaccumulate in aquatic food webs through different trophic levels (Green et al., 2016; H. K. Imhof et al., 2013; J. Li et al., 2018). More recent evidence from field based studies suggests that microplastics in aquatic systems are consumed predominantly by bivalves, crustaceans and some fish species (Law & Thompson, 2014; Sul et al., 2014). Research to assess how microplastic particles impact differing functional groups include laboratory studies of corals, Atlantic ditch shrimp, macroalgae, seagrasses, as well as various bivalve species.

Laboratory experiments on two scleractinian species of coral, *Montastraea cavernosa* and *Orbicella faveolate* found in the Caribbean, were investigated to establish the effects of microplastic particles on calcification and the retention of particles within the corals (Hankins et al., 2018). The microplastic particles elicit no calcification effects and all the particles ingested were recognised as foreign, and expelled by the corals within 48 hours (Hankins et al., 2018). However, exposure to microplastic particles may instigate disease in corals and contribute to tissue necrosis (Hankins et al., 2018). A study on the Atlantic ditch shrimp (*Palaemon varians*) showed an adaptation of the shrimp to expel unwanted particles (Saborowski et al., 2019). The shrimp was fed fluorescent microplastic particles of different sizes along with its normal food and ingested both fibres and beads with its food (Saborowski et al., 2019). The microbeads passed through the gut and were ejected in faeces, whereas the fibres were regurgitated through the oesophagus (Saborowski et al., 2019). Through evolution, invertebrates, such as shrimp, developed regurgitation as a response to unwanted and indigestible particles (Saborowski et al., 2019). The presence of microplastic particles on the surface of macrophytes are not well studied, however, as primary producers, macroalgae could possibly act as a vector of microplastic particles to higher trophic levels (Seng et al., 2020). Microplastic abundance were investigated on two subtidal macroalgae species *(Padina sp.* and *Sargassum ilicifolium*) and three species of seagrasses (*Cymodocea rotundata, Cymodocea serrulata* and *Thalassia hemprichii*) found in intertidal zones (Seng et al., 2020). A higher abundance of microplastic particles were present on seagrasses as opposed to macroalgae (Seng et al., 2020).

Additionally, several field-based studies on pelagic, demersal, and freshwater fish have been conducted internationally and in New Zealand. In 2013, research conducted by Lusher et al. on ten species of demersal (bottom-feeding) and pelagic (open water) fish in the English

Channel, found microplastic particles present in the digestive tract of all the species sampled. The primary morphotype belonged to microplastic fibres with 68% calculated, and the predominant polymers were polyamide, polyester and rayon (Lusher et al., 2013). Both, morphotype and polymer type were found in all the species, regardless of being demersal or pelagic, which is indicative of no bias when ingesting microplastic particles, whether unintentional or mistaken identity as prey (Lusher et al., 2013). Microplastic particles were also extracted and identified in the freshwater fish *Squalius cephalus* (European chub) in two urbanized rivers in Paris; the Marne and the Seine (Collard et al., 2018). The study showed that 25% of the 68 fish sampled ingested at least one microplastic particle. Furthermore, no microplastic particles were present in the tissue, however, microplastic particles were present in the liver of 5% of the fish species sampled. The primary morphotype present in the gut were microplastic fibres. An additional study in Europe investigated microplastic particles in the digestive tracts of two fish species from the River Thames, *Platichthys flesus* (European flounder) and *Osmerus eperlanus* (European smelt) (McGoran et al., 2017). The study showed that flounder, 75% of those sampled, ingested microplastic particles compared to 20% of the smelt which could be attributed to their differentiating feeding behaviours in the environment. Flounder feed on the benthos, whereas smelt are a pelagic species (McGoran et al., 2017).

The impacts of microplastic pollution on marine fish species in New Zealand is not well studied, however, records up to 2020 noted ingestion of anthropogenic matter (predominantly plastic) by 28 species (Horn, 2021). A high bioaccumulation of microplastic particles were observed in four New Zealand species (*Girella tricuspidate*, *Meuschenia scaber, Seriola lalandi* & *Lampris guttatus*) (Horn, 2021). The main diet of the two demersal species, *Girella tricuspidate* and *Meuschenia scaber*, consists of algae, therefore microplastic fibres

and fragments could easily be mistaken for natural food (Horn, 2021). The two pelagic species, *Seriola lalandi* and *Lampris guttatus,* have a main diet consisting of salps and cephalopods (Horn, 2021). Microplastic particles could be mistaken for natural prey of these two pelagic species due to similarities in morphology (Horn, 2021).

Two dominant feeding groups associated with soft sediments include, deposit-feeders and suspension-feeders (Wright et al., 2013). Deposit-feeders ingests large amounts of sediment, remove organic matter and microbes, and then excretes the sediment (pseudofaeces) (Anderson, 2008; Levinton, 2017; Nybakken & Bertness, 2005). Deposit-feeders, such as *Macomona liliana* feed on the surface or sub-surface sediments and affects sediment biogeochemistry due to their movement through the substrate (Gray, 2002; Levinton, 2017; Nybakken & Bertness, 2005).

Bivalves, such as *Macomona liliana* and *Austrovenus stutchburyi* inhabit soft sediment ecosystems and the feeding strategy of these organisms are key to ecosystem function because they directly affect the biogeochemistry of the sediment (Gray, 2002; Lopez & Levinton, 1987; Norkko et al., 2006). Suspension-feeders, such as *Austrovenus stutchburyi* and *Paphies subtriangulata,* feed on particles in the water column, and are active or passive feeders (Levinton, 2017). Trophic group amensalism is a complex interaction between suspension- and deposit-feeders, where deposit-feeders rework and destabilise, the sediment creating a stressful environment for suspension-feeders (Levinton, 2017; Nybakken & Bertness, 2005). Destabilising of the sediment by deposit-feeders leads to a decrease in food quality and may clog the gills of suspension-feeders (Adkins et al., 2014; Levinton, 2017). Furthermore, the presence of microplastic particles in the environment may exert additional pressure on suspension feeding communities by interfering with their feeding strategies.

Marine invertebrates such as bivalves are highly susceptible to microplastic ingestion due to the small size of the plastic particles (Wright et al., 2013). Microplastics need to have an extent of bioavailability to be ingested by lower trophic marine organisms (Wright et al., 2013). Several factors contribute to bioavailability such as the size, density, abundance and colour of microplastic particles (Wright et al., 2013). Lower trophic organisms will ingest any particles which are size appropriate to their natural food source, thus, ingesting microplastic particles as a mistaken case of prey identity (Jones et al., 2011; Wright et al., 2013). As previously discussed, the density of microplastic particles will determine their partitioning in the water column and marine sediments, thus exposing biota to microplastic particles in their direct habitat (Wright et al., 2013). Biofouled microplastic particles will sink and become available to biota feeding in sediment such as deposit feeders (Jahromi et al., 2021; Wright et al., 2013). An increased abundance of microplastic particles in the environment will amplify encounters by biota (Wright et al., 2013). Some pelagic invertebrates are chromatic rapacious predators capturing prey of a certain colour, consequently, microplastic particles resembling prey colour and size may be ingested (De-la-Torre et al., 2019; Wright et al., 2013).

Biological interactions enhance bioavailability of microplastics in the marine environment, for example, the lugworm *Arenicola marina*, a bioturbator, cycle the upper levels of sediment drawing microplastic particles into the sediment, rendering them available to infauna (Wright et al., 2013). Furthermore, once ingested by deposit-feeders, microplastics could be egested in faecal matter which then become bioavailable to filter-feeders and detritovores (Wright et al., 2013). Microplastics are therefore bioavailable to a range of invertebrate feeding guilds in the marine environment (Wright et al., 2013). Laboratory studies have demonstrated microplastic ingestion by a diverse assemblage of species and their associated larval forms (Prinz & Korez, 2020; Richardson et al., 2021; Wright et al., 2013). The highest concentrations

of microplastic particles in bivalve molluscs were found in their gut and tubules (Covernton et al., 2019; Wright et al., 2013).

There is an increase in evidence of microplastic bioaccumulation and transfer through different trophic levels in the food chain (Worm et al., 2017; Wright et al., 2013). Filter-feeders such as mussels accumulate microplastic particles, which are then transferred to their associated benthic predators, and in turn the predators consumed by humans (Worm et al., 2017). Smaller biota are at the most risk of physical impacts of microplastic ingestion. Microplastic ingestion can cause digestive tract blockages, starvation and reduced food consumption (Fendall & Sewell, 2009).

A laboratory investigation showed that microplastic particles ingested by mussels translocate to the circulation, within three days after ingestion (Browne et al., 2007). Two bivalve species of commercial value, *Mytilus edulis* (blue mussel) and *Cerastoderma edule* (cockle), were sampled on the Channel coastline in France and investigated for microplastic particle ingestion (Hermabessiere et al., 2019). The mussels and cockles encompassed between 0.76 and 2.46 particles per individual and between 0.15 and 0.74 per gram of tissue (Hermabessiere et al., 2019). The effects of microplastic pollution on bivalves is not well studied and understood in New Zealand, therefore this research is deemed a novel baseline study. Only one prior research was done in New Zealand on microplastic bioaccumulation in green-lipped mussels (*Perna canaliculus*) (Webb et al., 2019). Several locations were sampled for mussels across the North and South Island of New Zealand (Webb et al., 2019). Microplastic particles were extracted from mussels, with particle concentrations up to 1.5 particles per mussel calculated (Webb et al., 2019). Fragments were identified as the most predominant morphotype and polyethylene the primary polymer isolated (Webb et al., 2019).

The effects of microplastics on human and animal health have not been widely studied and a lack of knowledge is prevalent. Microplastic particles have been discovered in various matrices and human exposure as a direct consequence (Barboza et al., 2018; Karbalaei et al., 2018). Microplastic particles have been discovered in the atmosphere, drinking water and various food sources, with seafood considered the primary vector of microplastic pollution to humans (Barboza et al., 2018). Bioaccumulation of microplastic particles in the foodweb can ultimately exert adverse effects on human health and act as endocrine disruptors or carcinogenic agents (Baird, 2016; de Sá et al., 2018; Prata et al., 2020). Microplastic particles are vectors for an array of organic chemical pollutants, instigating additional disease and impose detrimental consequential effects on human health (Barboza et al., 2018). The size of microplastic particles should be taken into consideration when effects on human health are assessed (Barboza et al., 2018). The scientific community speculate that it is highly unlikely for microplastic particles greater than 150 µm to be absorbed or transferred across cell membranes and enter the circulatory system (Barboza et al., 2018). However, systematic exposure could be caused by microplastic particles smaller than 150 µm, which potentially can enter the lymphatic and circulatory systems by crossing cell membranes and translocate from the digestive tract (Barboza et al., 2018). Furthermore, research evidenced that microplastic particles transport various pathogens, such as *Vibrio spp.* and *Escherichia coli*, and are transferred to the human body through ingesting microplastic particles (Barboza et al., 2018; Bowley et al., 2021; Prata et al., 2020). Toxicokinetic studies are needed to fully understand the impacts of microplastic pollution on human health, including the associated transfer of pathogens and toxic chemicals by microplastic particles present in seafood (Barboza et al., 2018; Bowley et al., 2021). Several discrepancies of the effects of microplastic particles on human health exists, and therefore a study area that needs further investigation

to provide a better understanding of the topic (Barboza et al., 2018; Bowley et al., 2021). Exposure gradients in seafood to humans, and other food products, are relatively undefined and warrants for further investigations (Barboza et al., 2018; Bowley et al., 2021).

The build-up of plastic microparticles in both our waterways and marine environments are of concern to New Zealand, however, the extent of this issue has yet to be quantified. Studies are in progress to quantify the issue and raise public awareness (Clunies-Ross et al., 2015; Gregory, 1978). To eliminate the potential problem microplastics are causing to the marine environment, we first need to investigate the spatial extent of microplastics as well as their effects on species living in these coastal ecosystems.

The impacts of microplastic pollution in oceanic ecosystems are of a concern for ecological functioning, but more so for food safety and the effects translating to human health (Barboza et al., 2018; Bowley et al., 2021). Mātauranga Māori signifies "intergenerational knowledge in a contemporary way" (Crawford, 2009; Hikuroa, 2017). Māori have a strong cultural connection to water and believe it has a life force (mauri), thus plastic pollution has significant effects on beliefs of cultural wellbeing (Crawford, 2009; Hikuroa, 2017). Highly significant cultural practises such as kaimoana (fish and shellfish) gathering by local iwi can directly be affected by microplastic pollution. Ongoing research is therefore crucial to ensure a "safe" food resource for the local community in the Bay of Plenty, as well as communities throughout New Zealand and on a global scale.

1.2 Study Objectives

This research is an investigative study to identify, quantify and characterise plastic microparticles present in sediment and bivalves (*A. stutchburyi, M. liliana* and *P. subtriangulata*) in the Tauranga Harbour. Research was focused on three objectives; (1) to

extrapolate any variances in microplastic pollution between the Tauranga Harbour System, Ohiwa Harbour System and the eastern Bay of Plenty coastline in sediment and bivalves, (2) - record variances in microplastic pollution in sediment along transects between the intertidal and high tide marks at estuarine and coastal locations, (3) record the presence of microplastic particles in *A. stutchburyi*, *M. liliana*, and *P. subtriangulata* and (4) identify variances in the amount of microplastics between these species. Baseline data collected herein will provide an opportunity for ongoing microplastic research in the Bay of Plenty Region and wider New Zealand.

1.3 Research Significance

The short-term goal is to improve our understanding of the nature and origins of plastic microparticle contamination, which in turn can then inform establishment of policy and coastal management plans aimed at minimizing plastic microparticles in our aquatic environment.

Chapter 2

Methods

2.1 Study Site Description

The Bay of Plenty shoreline is vast and extends from Waihi to the East Cape near Lottin Point and encompass several estuaries, 10 large rivers in the catchment, and two major harbours (Ōhiwa and Tauranga) (Clark et al., 2018; Sinner et al., 2011). The aquaculture industry is expanding in the Bay of Plenty with three existing oyster farms located in Ōhiwa Harbour and a 3,800-hectare marine farm off the coast close to Ōpōtiki (*Aquaculture*, n.d.).

Ōhiwa Harbour is a 24 km^2 estuary located between two barriers, the Ohope spit in the west and the Ōhiwa spit in the east (Richmond et al., 1984). Tidal flats are prevalent throughout the harbour with some saltmarsh and mangrove stands present (Richmond et al., 1984). The harbour is tidal and current dominated with lower energy propagating towards inner harbour areas (Richmond et al., 1984). Several biological communities exist within the harbour contributing to an abundant diversity of species (Richmond et al., 1984). Land use is varied throughout the harbour with low urbanisation and some pastoral land observed (Richmond et al., 1984).

Tauranga Harbour is one of New Zealand's largest natural harbours and encompass an area of 218 km^2 (Clark et al., 2018; Friday et al., n.d.; Sinner et al., 2011). Tauranga Harbour is an immense tidal estuary, as well as having the largest export port in New Zealand (Sinner et al., 2011). The Harbour catchment includes an area of 1,300 km^2, with 27 main rivers and 46 smaller streams (Sinner et al., 2011). The entirety of the harbour has been classified as an

outstanding natural feature and landscape (ONFL) and serves as a valuable resource to local iwi for kaimoana gathering, as well as holding spiritual significance (Clark et al., 2018; Friday et al., n.d.; Sinner et al., 2011). The catchment in Tauranga Harbour and surrounding area is utilized for several activities, with landcover types including indigenous forest and scrub, exotic forest and scrub, horticulture, pasture, urban, saltmarsh, mangrove, and wetlands (Clark et al., 2018; Friday et al., n.d.; Sinner et al., 2011). Two barrier tombolo's (Bowentown & Mount Maunganui) and a barrier island (Matakana Island) provision shelter from the Pacific Ocean (Sinner et al., 2011). Tidal flow is strong through deep channels at either side of Matakana Island (Sinner et al., 2011). Furthermore, the harbour encompass a diverse assemblage of species contributing to an abundant biodiversity of fauna and flora (Sinner et al., 2011).

Figure 2. *Sampling locations in the A) Tauranga Harbour System, Maketu Estuary, Little Waihi Estuary and B) the eastern coastline, Bay of Plenty, New Zealand.*

2.2 Study Species

Three bivalves species were selected based on their feeding modes and location in the marine environment. *Austrovenus stutchburyi* (cockle/ tuangi) is a filter feeding species, and *Macomona liliana* (wedge shell/ Hanikura) a deposit feeder, both occurring in inner estuarine areas (Adkins et al., 2014; Covernton et al., 2019). Bivalve beds of *Paphies subtriangulata* (surf clam/ tuatua) occur in soft sediment at the outer coast (Norkko et al., 2006). Selecting these species allowed for comparison between filter feeders and deposit feeders in two different habitats.

2.3 Sampling Design

2.3.1 Sediment Sampling

In January and November 2020, sediment samples were collected from 29 locations across the Bay of Plenty, in New Zealand (Fig. 2). Suitable sampling sites were selected along the beach or estuary at each location. Systematic sampling was conducted along a tidal gradient. Sites were selected based on areas with the greatest accumulation of washed-up debris. The inter-tidal and high tide marks were identified for sampling. Firstly, three areas were marked on a transect along the high-tide zone (x = 30m apart) and sampling of the marked areas were executed from the right-hand side facing the ocean (Fig. 3). The samples were labelled as high tide (HT)A, HTB and HTC. Similarly, samples were collected along the inter-tidal zone (Y = 30m, the distance between the high and inter-tidal sampling mark) and labelled inter-tidal (IT)-1, IT-2 and IT-3 (Fig. 3).

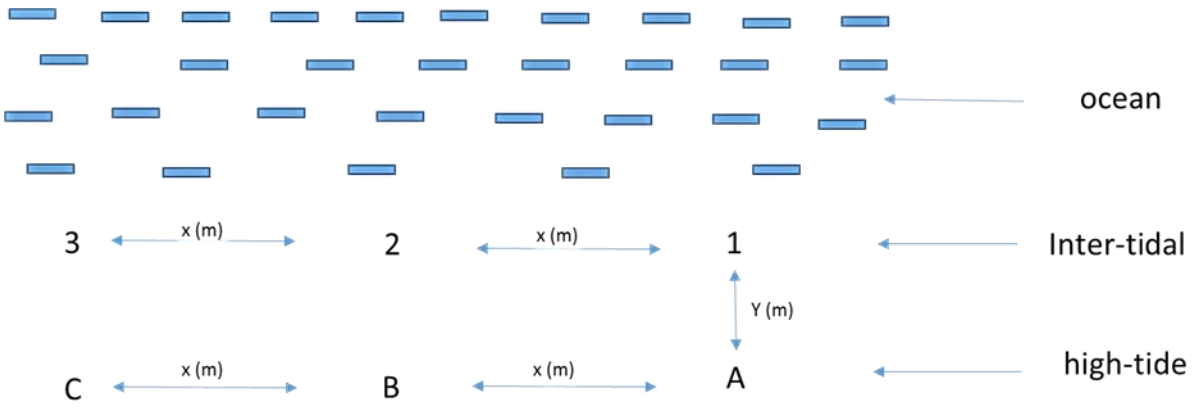

Figure 3. *Sampling on a transect along the intertidal and high-tide marks where X is representative of the distance (m) between the quadrats and Y is representative of the distance (m) between the inter-tidal and high-tide marks.*

A quadrat (0.5 m x 0.5 m) was placed on the selected sampling area for example, HTA. Five samples were collected from inside the quadrat as shown in Fig. 4 to collate an average for the sample. Large organic matter (such as large leaves, twigs, and shells) were removed from within the quadrat that may obstruct the sampling process.

Each sample was collected using an automated stainless-steel corer (5cm wide x 6cm deep) placed on the substrate and firmly inserted to a depth of 6 cm with the top rim in line with the substrate bed. Care was taken, to not press the stainless-steel corer too far into the substrate as to avoid inconsistency in the sampling process. The corer was slowly removed keeping the sediment core intact, and the excess sediment removed from the bottom of the inverted corer using a stainless-steel butter knife. The stainless-steel corer was cleaned prior to each sampling routine to avoid any contamination. Samples from the remaining area within the quadrat were also collected. Each jar contained a total of five samples from within the quadrat. Aluminium foil was placed over the jar before securing the lid to further circumvent contamination.

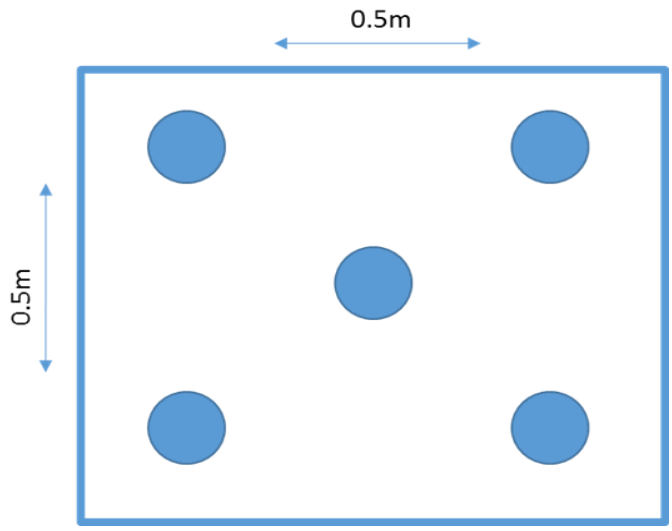

Figure 4. *Sampling sediment cores within the wooden quadrat (0.5m x 0.5m).*

2.3.2 Bivalve Sampling

In January and November 2020, bivalve samples were collected from 31 locations across the Bay of Plenty, in New Zealand (Fig. 2). Bivalve sampling locations were chosen to be representative of the northern, mid, and southern areas of the Tauranga Harbour. These locations enabled a greater spatial analysis and investigation regarding anthropogenic pressure within the harbour. Additional locations were also selected on the open coast such as Tuapiro Point Beach, Mount Maunganui main beach and Omanu (Te Maunga WWTP sewage outfall).

A maximum of 15 individuals were sampled from each species at a given location to eliminate unnecessary exploitation and utilisation of biological samples. Bivalves were collected at random during low tide. Specimens were placed in clean glass jars, then filled with seawater (covering the bivalves) and labelled. Aluminium foil was placed over the jar before securing the lid to avoid contamination. The specimens were frozen at -20^{o}C post-sampling without depuration to ensure the retention of any ingested microplastic particles.

2.4 Laboratory Processing

2.4.1 Sediment Processing

Sediment collected from each site was weighed for microplastic separation (Appendix 1). 400 g of the wet sediment was weighed and placed into the beaker. The beaker with wet sediment was covered with foil to limit plastic contamination from the surrounding environment and placed into an oven at 70^{o}C (12 hr) until no weight change was observed. Dried sediment from each beaker was weighted and the percentage moisture content (mc) calculated. A highly saturated solution (concentration = 5 mmol/L, density = 1.15 g/mL) of Sodium Chloride (NaCl) was prepared and 300 ml of the solution added to the dried sediment The NaCl solution was prepared as follows: 584.4 g of NaCl was weighed and made up to 2 L using Milli-Q-water (MQ). MQ water has a high level of purification. Once the NaCl was dissolved the solution was filtered to remove any impurities. The sand-NaCl mixture was then stirred manually for ten minutes using a glass rod. The mixture was allowed to settle for one hour to float the microplastic particles out from sediments. The rationale supporting this methodology is explained here: less dense (light) microplastic particles will float out from the sediment and float on top of the high density 5 mmol/L NaCl solution. All floating material from the beaker was transferred to a 150 µm sieve and the sides of the beaker rinsed with MQ water to transfer all residual solids to the sieve. All large debris such as shells, twigs, and other organic material (>5 mm) were removed using forceps and rinsed off over the sieve with MQ water before being discarded. Rinsing the debris ensured that no microplastic particles adhering to the debris were discarded. All solids collected on the 150 µm sieve were transferred to a clean, weighed beaker. MQ water was used to transfer all materials from the sieve screen into the beaker and the sides of the beaker washed down (a limited amount of water was used in this step to ensure prompt evaporation of the water in the oven). The beaker was

covered with foil (holes were created in the foil to aid evaporation) and placed in an oven at 70^{o}C (24 hr). The mass (g) of all microplastic and organic matter was enumerated by subtracting the tared beaker weight from the beaker with solids weight (Appendix 1).

Wet peroxide oxidation (WPO) process

The next step in the processing methodology involved a wet peroxidation process. This step was essential for the successful removal of all organic material. Caution was taken as this was a highly reactive mixture. An aqueous solution of 0.05M Fe (II) was prepared by adding 7.5 g of iron sulphate (Fe_2SO_4.7H2O [=278.02g/moll]) to 500 mL of deionised water and stirred on a magnetic plate till the iron sulphate was completely dissolved, where after 3 mL of concentrated sulphuric acid was added to the solution. The iron sulphate (20 mL) was added to the beaker containing the microparticles and organic matter. Hydrogen peroxide (20 mL of 30% concentration) was added to the beaker and the mixture allowed to stand at room temperature for five minutes. The beaker was placed in a 75^{o}C water bath and covered with a watch glass. Bubbles appeared and subsided gradually (this mixture can boil violently when heated at >75^{o}C but the reaction can be stopped by adding MQ water). The beaker was mixed at 40rpm at 75^{o}C for 30 minutes. Another 20 mL of the 30 % H_2O_2 was added after 30 minutes as more organic matter was still visible. The peroxidation step was repeated until no natural organic matter was visible in the solution. The amount (ml) of H_2O_2 added was and 2.5 g of Merck salt added per 10 mL of the sample (Appendix 1). This step increased the density of the aqueous solution. The mixture was heated in the water bath until the Merck salt dissolved (~ca. 1-1.5 hours).

Density separation as per NOAA Protocol

The solution from the wet peroxide oxidation was transferred to a density separator funnel. The beaker was thoroughly rinsed with the 5 M NaCl solution to transfer all the solids to the density separator. The separator was covered loosely with aluminium foil and left to settle overnight. A quick flush was performed to get rid of any sand and unwanted particles that settled in the bottom of the separation funnel. The solution was then drained onto a PCTE (polycarbonate) filter membrane attached to a vacuum. The sides of the separation funnel were well washed with MQ water to ensure all solids got transferred to the membrane. The surface of the filter membrane was washed to dissolve remaining NaCl crystals. The membrane was placed on a labelled glass Petri Dish and dried overnight.

2.4.2 Bivalve Processing

Samples were allowed to defrost prior to processing (± 12–24 hours). Each bivalve was measured with a caliper and weighed with shell. The shellfish were opened using a scalpel to cut the adductor muscle. The bivalves were grouped into fives, thus providing three replicates of each species per location. All the tissue scooped out, weighed, and added to a 250 ml flask. A 10% potassium hydroxide (KOH) solution at 3 x the tissue volume was added to the flask and incubated at 50°C (48 hr.). Shellfish weight and length were recorded (Appendix 2). Filter paper was fitted in a Buchner Funnel and the entirety of the KOH solution filtered through using a vacuum. The filter paper was carefully removed using metal forceps and placed into a labelled glass Petrie Dish. The filter paper was allowed to dry prior to microscopic analysis.

2.5 Microscopy

A stereomicroscope (Olympus SZ61) and visual light were used for microscopic analysis for both the sediment and bivalve samples. The Petri dish without its lid was placed under the

microscope to view the membrane and particles. A small mark was made inside the Petri Dish at the top to assist with orientating the sample for viewing. The membrane was scanned from left to right and again from right to left. Microplastic particles were identified and counted for sediment and bivalves. Three primary morphotypes of microplastic particles were identified: films, fragments, and fibres. Standardised microscopic protocol as described in the MERI (Marine & Environmental Research Institute) guide was used to aid the accurate identification of microplastic particle (Shim et al., 2017). Images were captured using an Olympus EP50 camera (Appendix 3).

2.6 Quality Assurance and Quality Control (QA & QC)

Several measures were taken throughout all the sampling, processing, and analytical steps to ensure minimisation of plastic contamination to samples.

2.6.1 Sampling QA and QC

Cotton clothing free of polyester were worn during sampling which prevented plastic fibres from being transferred to the sampling area or sampling jars. Two people sampled downwind from the quadrat which minimised the probability of contamination. The quadrat was placed on undisturbed substrate e.g., no footprints, and at a set distance away from the public. All sampling equipment used consisted of stainless-steel, wood or glass, and the glass jar was covered with foil before closing the lid to further prevent plastic contamination. Glass jars were rinsed prior to sampling with deionised water and air dried to ensure that no microplastics were present in the jars upon sampling.

2.6.2 Laboratory processing QA & QC

The bench top and fume hood were wiped clean before opening the sample jars for processing as smaller microplastic particles are airborne. NaCl solution was filtered to remove

plastic particles present in the NaCl (pool salt was used for the 5 Mol NaCl solution). Deionised and MQ water were used throughout the procedure as tap water may contain microplastic particles which may be transferred to samples during processing. A cotton lab coat was worn with all personal clothing well-covered underneath. The beakers and separation funnels were covered with aluminium foil to keep out any plastic particles. All laboratory equipment used consisted of glass, and all dirty glassware hand washed, and air dried away from other equipment used in the lab. The fume hood and oven were exclusively booked for the microplastic project to avoid contamination from other work conducted in the laboratory. Open Petri dishes were placed at random in the laboratory to ensure no contamination from airborne microplastic particles occurred. Temperatures of the oven and water bath were continuously monitored to ensure that standard protocol was adhered to.

2.6.3 Microscopy QA and QC

The microscope bench and area were wiped clean before opening the Petri dishes containing membranes. Metal equipment such as forceps and needles were used to prod the suspected microplastic particles.

2.6.4 General quality control measures

Six validation samples with a known amount and size of microplastic particles were processed as part of quality assurance to ensure the protocols used was effective and accurate. All the team members received sufficient training and a briefing about the standard protocols before the commencement of the project. This ensured consistency throughout the project. Methodologies were discussed with the research supervisors and modifications made to fit the scope of this project.

2.7 Statistical analysis

Statistical analyses were done using Excel and Primer software packages. ANOVA (analysis of variance) was performed to demonstrate statistically significant differences of microplastic pollution in sediment between sampling locations and tidal zones. Furthermore, ANOVA was used in demonstrating variances and differences between bivalve species at different localities. The ANOVA provisioned descriptive statistics such as a *p* value, which enabled me to accept or reject the null hypothesis (*p* value <0.05). A Bray-Curtis similarity was calculated for the sediment locations using Primer.

Chapter 3

Results

3.1 Accumulation Rates in Marine Sediment

3.1.1 Accumulation in sediment

Microplastic accumulation were highest at sites with high coastal density and near wastewater outfalls. The mean number of microplastics per m^2 was the greatest in the intertidal zone at Karewa Parade, Papamoa East (11087/m^2) (Fig. 5). Furthermore, high numbers of microplastics per m^2 were extrapolated at the intertidal zone of the Omanu sewage outfall (2800.2/m^2) and intertidal zone at Papamoa Domain (3343.9/m^2) (Fig. 5). High numbers of microplastic particles were also measured at the intertidal zone at Ohope Beach (2487.3/m^2) (Fig. 5). The lowest number of microplastics per m^2 was observed in the intertidal zone at Matakana Island site 1 (63.5/m^2), which are located at the southern end of the island (Fig. 5). All the sampling locations at Matakana Island were indicative of lower numbers of microplastic particles in comparison to the other sampling areas. There was a statistically significant difference in the mean microplastic number per m^2 between the different sampling locations (***P*** value < 0.05, ANOVA), (Table 1). However, there was no statistically significant difference between the intertidal and high tide zones of all the sampling locations (***P*** value > 0.05, ANOVA), (Table 1).

Table 1. *Descriptive statistics for the number of microplastics found per m^2 at the various sampling locations.*

ANOVA

Source of Variation	*df*	*F*	*P-value*	*F crit*
HT/IT	1	1.1	0.3	4.2
Sampling Locations	27	1.9	**0.04**	1.9

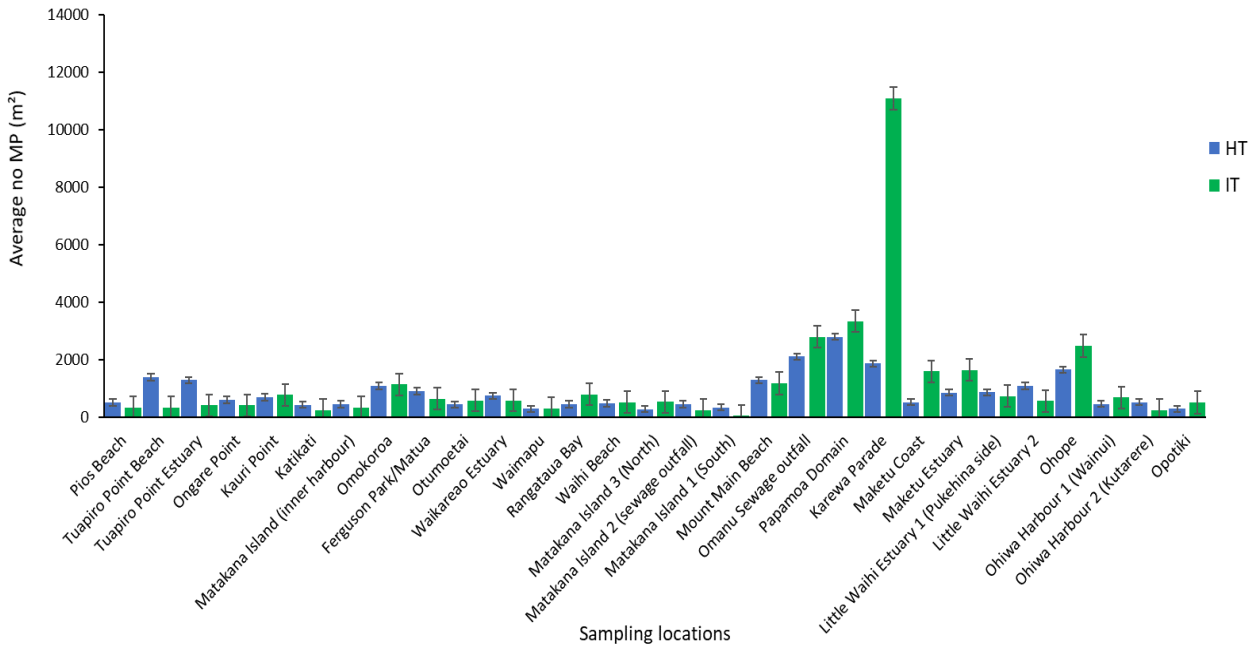

Figure 5. *The average number of microplastics per m², extrapolated at the intertidal (IT) and high tide (HT) zones of each sampling location (Error bars ± SE).*

3.1.2 Accumulation in sediment per kg ^{1}

The mean number of microplastics found per kg of dry weight (kg ^{1} DW) was the greatest in the intertidal zone at Karewa Parade, Papamoa East (157.1 particles per kg ^{1} DW), with the least observed in the intertidal zone at Matakana Island site 1 (1 particle per kg ^{1} DW) (Fig. 6). There was similarity between the mean number of microplastics per kg of dry weight in the high tide and intertidal zones at Papamoa Domain and the Omanu sewage outfall (Papamoa Domain; HT = 41.6; IT = 49.1 & Omanu sewage outfall; HT = 44.7; IT = 33.5) (Fig. 6). A greater variance of the mean number of microplastics per kg of dry weight were found between the high tide and intertidal zones at Karewa Parade with 157.1 particles found in the intertidal zone and 32.5 particles in the high tide zone (Fig. 6). There was a statistically significant difference in mean microplastics per kg of dry weight between sampling locations (***P*** value < 0.05, ANOVA), with no statistically significant difference between the intertidal and high tide zones (***P*** value > 0.05, ANOVA), (Table 2).

Table 2. *Descriptive statistics for the number of microplastics found per kilogram of dry weight at the various sampling locations.*

ANOVA

Source of Variation	*df*	*F*	*P-value*	*F crit*
HT/IT	1.00	0.96	0.34	4.21
Sampling locations	27.00	2.29	**0.02**	1.90

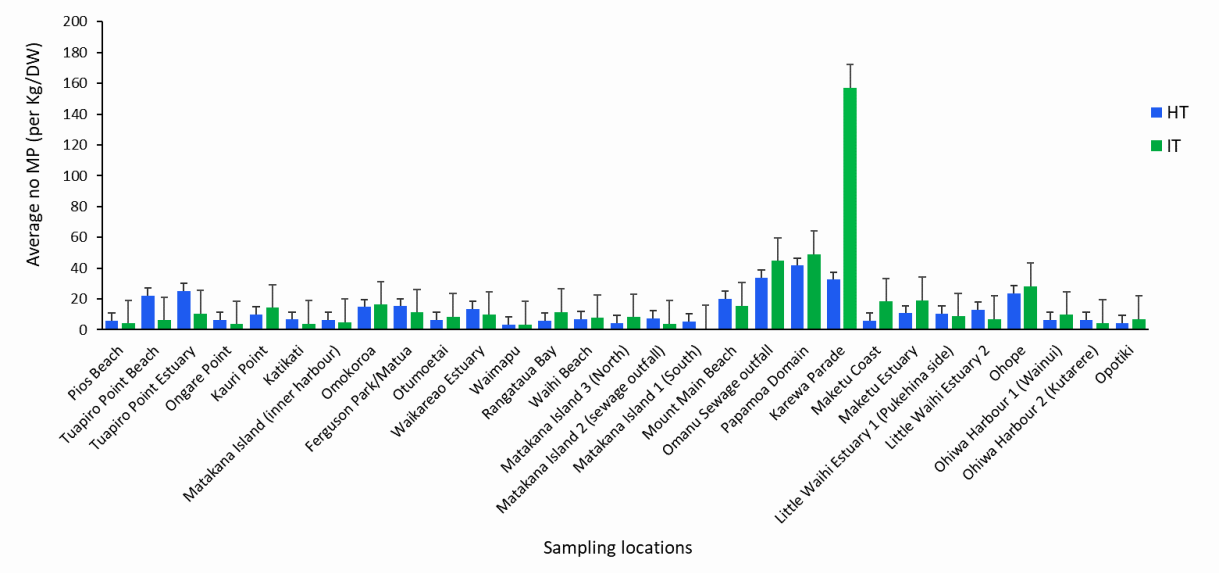

Figure 6. *Average number of microplastic particles per kilogram of dry weight, extrapolated at the intertidal (IT) and high tide (HT) zones of each sampling location (Error bars ± SE).*

3.1.3 Bray-Curtis similarity for microplastic sediment accumulation

Three primary groups are noted to be grouped together on the plot upon multivariate analysis on the square-root (Fig. 7). Groups are clustered based on populated areas and sewage outfalls (Fig. 7). Evidently, the greatest amount of microplastic accumulation in the sediment and an outlier is observed at Karewa Parade, a highly populated beach (Fig. 7). Similarly, two of the sewage outfalls are clustered together (Fig. 7). The lowest accumulation of microplastic particles are observed at Matakana Island 1 (south). Sites furthest to the right on the first principal axis exemplifies less populated areas (Fig. 7).

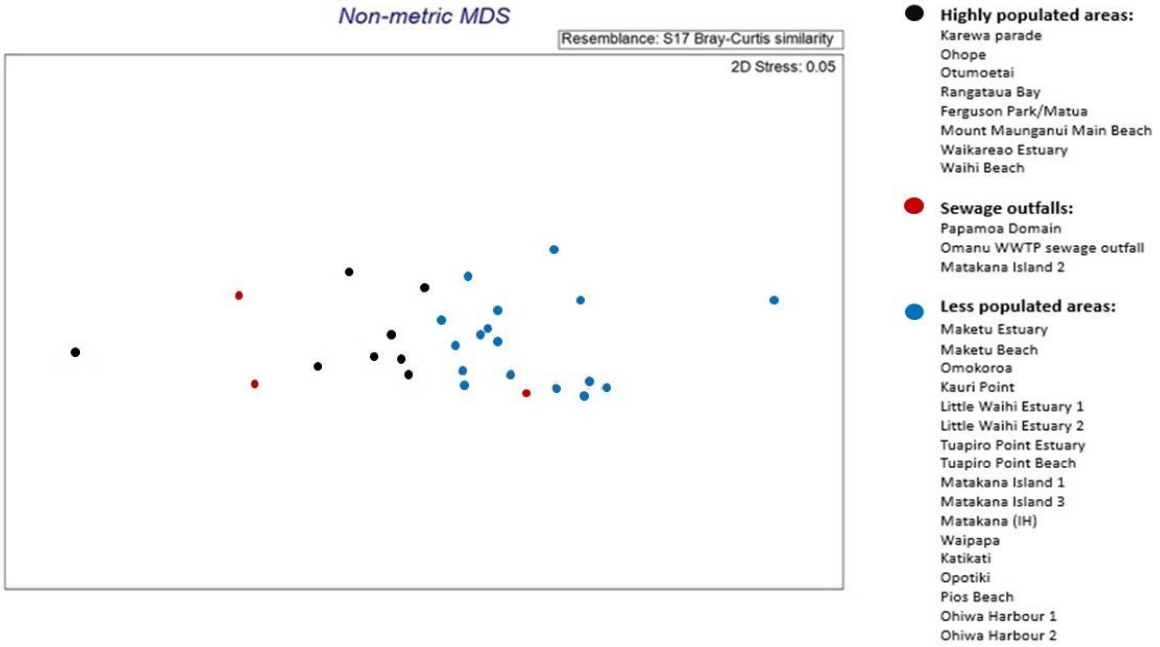

Figure 7. *Non-metric MDS plot based on the Bray-Curtis similarity matrix describing similarity of microplastic pollution in sediment at the intertidal zone of the sampling locations.*

3.1.4 Comparison between Tauranga Harbour, Ōhiwa Harbour, and the eastern coastline of the Bay of Plenty

The mean number of microplastics per m^2 was the greatest in the intertidal zone of the eastern coastline (2066.9 m^2) (Fig. 8). Furthermore, high numbers of particles per m^2 (1133.4 m^2) were extrapolated at the high tide zone of the eastern coastline (Fig. 8). Ōhiwa Harbour, (HT = 504.6 m^2, IT = 477.7 m^2) had slightly less microplastic particles than Tauranga Harbour (HT= 673.9 m^2, IT= 571.2 m^2) (Fig. 8). There was no statistically significant difference in microplastic pollution between Ōhiwa Harbour, Tauranga Harbour, and the eastern coastline, as well as no statistical difference between the hightide and intertidal zones (***P*** value > 0.05, ANOVA) (Table 3).

Table 3. *Descriptive statistics for the number of microplastics found per m^2 at the Tauranga Harbour System, Ohiwa Harbour System, and eastern coastline in the Bay of Plenty, New Zealand.*

ANOVA

Source of Variation	*df*	*F*	*P-value*	*F crit*
HT/ IT	1	0.6	0.5	18.5
Sampling locations	2	4.4	0.2	19.0

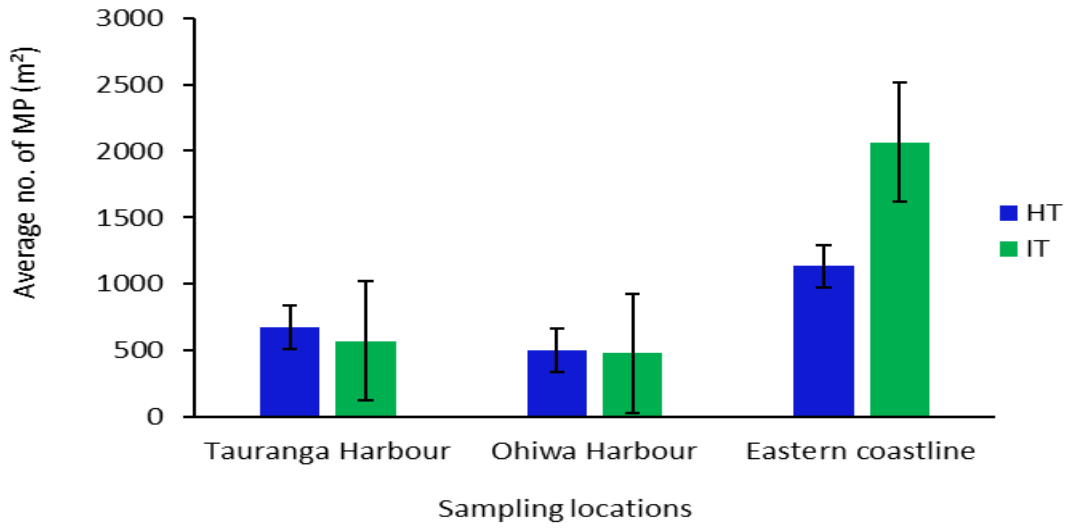

Figure 8. *The average number of microplastic particles per m^2, cumulatively extrapolated at the intertidal and high tide zones of the eastern coastline, Tauranga Harbour and Ohiwa Harbour (Error bars ± SE).*

3.1.5 Morphotypes accumulated in sediment

The microplastics identified in sediment were broadly categorised into fibres, fragments, and films, with some showing distinct evidence of weathering. The sizes measured for all the particles ranged between 150 µm to 5 mm. The category with the greatest number of microplastics was fibres (75%), followed by fragments (23%) and the lowest percentage extrapolated belonged to microplastic films (2%) (Table 4). Karewa Parade showed the highest number of plastic fragments (150 particles), and Papamoa Domain showed 26 fragmented particles (Table 4). The highest number of microplastic films were extracted at

Ferguson Park in Matua (4 particles) (Table 4). Plastic fibres were widespread across most sampling locations; however, the highest number of plastic fibres were present at Papamoa Domain (73 particles) and 68 particles at Karewa Parade (Table 4). Furthermore, a high accumulation of plastic fibres were also extrapolated at the Omanu sewage outfall (65 particles).

Table 4. *The proportion of the three morphotypes of microplastic particles (fibres, films & fragments) collectively extrapolated from sediment at all sampling locations.*

Locations	Fragments	Films	Fibres
Mount Main Beach	0	0	39
Omanu Sewage outfall	13	0	65
Omokoroa	5	2	26
Ferguson Park/Matua	7	4	14
Waikareao Estuary	2	3	18
Tuapiro Point Beach	3	0	27
Tuapiro Point Estuary	0	0	28
Karewa Parade	150	0	68
Papamoa Domain	26	0	73
Maketu Coast	2	0	25
Maketu Estuary	3	1	26
Little Waihi Estuary 1	1	0	20
Little Waihi Estuary 2	0	3	17
Ohope	0	0	55
Ōtumoetai	1	0	13
Kauri Point	0	0	23
Katikati	0	0	11
Ōpōtiki	0	0	12
Waipapa	0	1	7
Pios Beach	0	1	11
Rangataua Bay	0	0	17
Ōhiwa Harbour 1 (Wainui)	0	0	15
Ōhiwa Harbour 2 (Kutarere)	1	0	10
Matakana Island 1 (South)	0	0	7
Matakana Island 2 (sewage outfall)	0	0	12
Matakana Island 3 (North)	0	0	13
Matakana Island (inner harbour)	0	0	12
Waihi Beach	2	0	13
Total # of particles	**216**	**15**	**677**
Percentage	**23**	**2**	**75**

3.1.6 Fourier Transform Infrared Spectroscopy (FTIR) – sediment accumulation

The FTIR results indicate high accumulation rates (40%) of cellulose and regenerated cellulose (cotton, rayon, or cellophane) (Table 5). Furthermore, 37% inorganics (calcium carbonate, magnesium silicate and silica) are noted, as well as 13% polyvinylchloride and 10% polyamide (nylon) (Table 5).

Table 5. *Fourier transform infrared spectroscopy results; Inorg is inorganics (calcium carbonate, magnesium silicate and silica), C & RC is cellulose and regenerated cellulose (cotton, rayon, or cellophane), PVC is polyvinylchloride and PA is polyamide/nylon. See appendix* 1 *for full description of abbreviations.*

Particle type	Percentage
PE	0
PP	0
PET	0
PA	10
PMMA	0
C&RC	40
PU	0
PS	0
PVC	13
SY-ACN	0
ACRY	0
RUB	0
Epoxy	0
PVA	0
Cell	0
Inorg	37
Org	0
Incon	0

3.1.7 Validation of microplastic particles extraction method from sediment

Prior to processing, three samples were spiked with 30 of each type of plastic particle (PVC, PET, HDPE, PS, PA, PP and fibres < 2 mm), totalling 240 particles per sample. The results from the validation showed a high recovery rate for all samples and the various types of plastic. Coloured particles used included 100–500 µm of PVC, PET, HDPE, PS, PA, PP, and fibres < 2

mm. It can be concluded from these results, that the methodology used for microplastic extraction was accurate, due to a high recovery rate (>98 %) as displayed in Table 6.

Table 6. *Validation sample recovery results; three beakers with spiked samples; average count from three samples, SD, and percent recovery.*

Beaker	count 1	count 2	count 3	Ave. count	SD	Recovery (%)
Spike A	235	237	239	237	1	99
Spike B	239	236	238	238	1	99
Spike C	231	237	236	235	1	98

3.2 Bioaccumulation Rates in Bivalves

3.2.1 Total number of microplastic particles found in bivalve tissue (wet weight)

The greatest total number of microplastic particles has been extracted from *M. liliana* at all sampling locations (Fig. 9). The highest number of microplastics was present in *M. liliana* sampled at Rangataua Bay (23). Tuapiro Point Estuary also demonstrated high levels of particles in *M. liliana* (11), (Fig. 9). The lowest number of microplastic particles in *M. liliana* was observed at Waikareao Estuary (2) and Matahui (2), (Fig. 10).

The greatest number of microplastic particles in *A. stutchburyi* was observed at Rangataua Bay (10) and Maketu Estuary (9), with the least at Welcome Bay/ Rotary Park (1), Tuapiro Point Beach (1), Ohiwa Harbour site 1 (Wainui), and Matakana Island site 3 (Fig. 9).

The greatest number of microplastic particles in *P. subtriangulata* was observed at Matakana Island site 2 (sewage outfall) (11) and the inner harbour at Matakana Island (10) (Fig. 9). The

southern end of Matakana Island (site 1) showed the least particles (1) in *P. subtriangulata* (Fig. 9). Bioaccumulation of microplastic particles in the bivalves is spatially widespread (Fig. 9). There was a statistically significant difference between the total amount of microplastic particles found in *M. liliana*, *A. stutchburyi, P subtriangulata* (***P*** value < 0.05, ANOVA), but no statistically significant difference between sampling locations (***P*** value > 0.05, ANOVA) (Table 7).

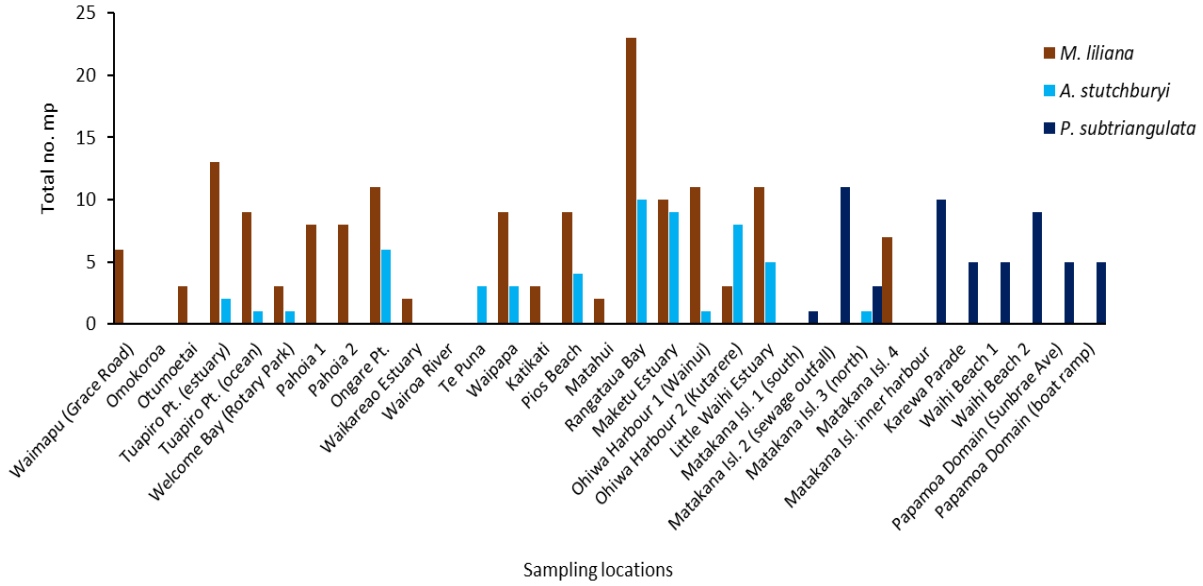

Figure 9. *The total number of microplastic particles extracted from M. liliana, A. stutchburyi & P. subtriangulata at each sampling location within the Tauranga Harbour and eastern coastline.*

Table 7. *Descriptive statistics for the total number of microplastics found per species at the different sampling locations.*

ANOVA

Source of Variation	*df*	*F*	*P-value*	*F crit*
Species	2	5.922	**0.004**	3.150
Locations	30	0.922	0.587	1.649

3.2.2 Average number of microplastics per gram of tissue in *M. liliana* and *A. stutchburyi*

The greatest average number of microplastic particles per gram of tissue have been extracted from *M. liliana* at all sampling locations, with the least from *A. stutchburyi* (Fig. 10). The

highest number of microplastics per gram of tissue, were present in *M. liliana* sampled at Tuapiro Point Estuary (1 particle per gram), as well as Maketu Estuary (1 particle per gram), (Fig. 10). The lowest number of microplastic particles per gram of tissue in *M. liliana* was observed at Waikareao Estuary, Matahui, Ōhiwa Harbour site 2 (Kutarere) with 0.1 particles per gram of tissue at each location (Fig. 10).

The greatest number of microplastic particles in *A. stutchburyi* was observed at Waipapa (1.2 particles per gram of tissue), with the least at Matakana Island site 3 (0.07 particles per gram of tissue) (Fig. 10). There was a statistically significant difference between the number of microplastic particles found per gram of tissue in *M. liliana* and *A. stutchburyi* (***P*** value < 0.05, ANOVA), as well as a statistically significant difference between sampling locations (***P*** value < 0.05, ANOVA) (Table 8).

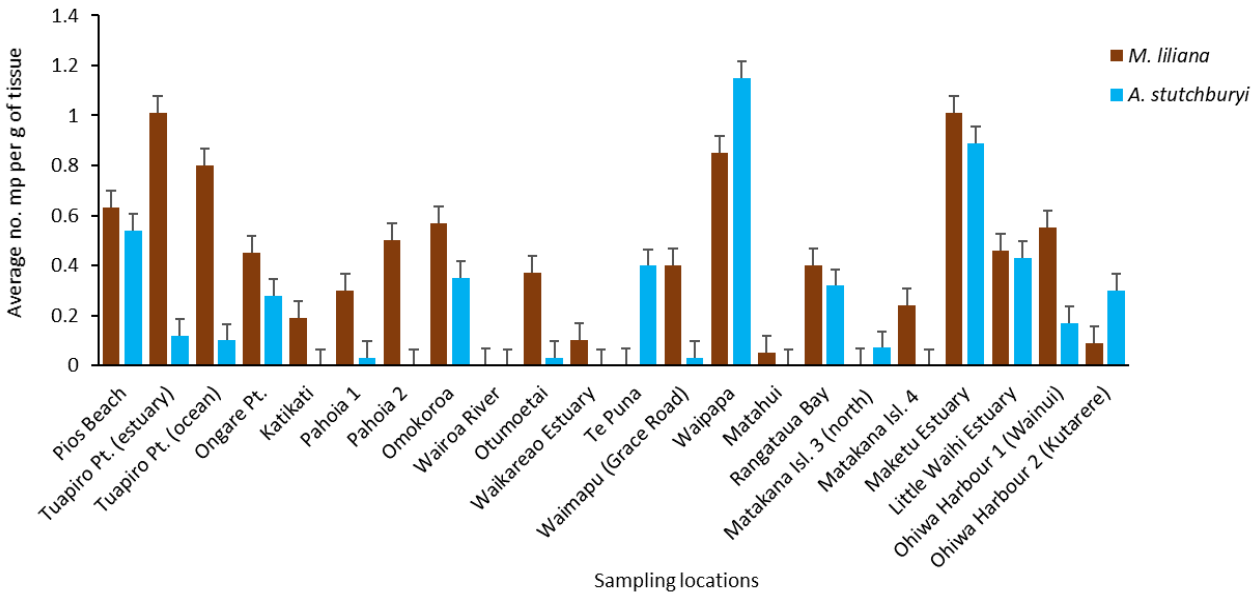

Figure 10*. The total number of microplastic particles extrapolated per gram of tissue from M. liliana and A. stutchburyi at each sampling location within the Tauranga Harbour and eastern coastline.*

Table 8. *Descriptive statistics for the number of microplastic particles found per gram of tissue in M. liliana and A. stutchburyi at the different sampling locations.*

ANOVA				
Source of Variation	*df*	*F*	*P-value*	*F crit*
Species	1	7.119	0.014	4.301
Sampling locations	22	3.326	**0.003**	2.048

3.2.3 Average number of microplastics per gram of tissue in *P. subtriangulata*

The highest average number of microplastics per gram of tissue, were present in *P. subtriangulata* sampled at Matakana Island site 2 (sewage outfall) (0.23 particles per gram), as well as Waihi Beach site 2 (0.22 particles per gram), (Fig. 11). The lowest number of microplastic particles per gram of tissue in *P. subtriangulata* was observed at Matakana Island site 1 (0.03 particles per gram) (Fig. 11). All the locations where *P. subtriangulata* were sampled demonstrated microplastic contamination within this species, with values ranging between 0.03 and 0.23 particles per gram of tissue (Fig. 11). There was no statistically significant difference between the average number of microplastic particles found in *P. subtriangulata* per gram of tissue at the different sampling locations (***P*** value > 0.05, ANOVA) (Table 9).

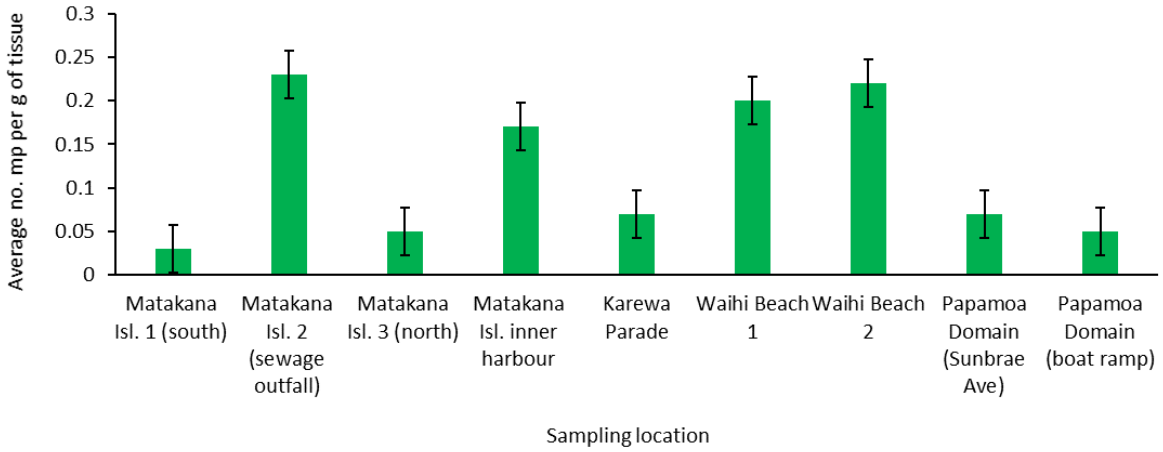

Figure 11. *The total number of microplastic particles extrapolated per gram of tissue from P. subtriangulata at each sampling location within the Tauranga Harbour and eastern coastline.*

Table 9. *Descriptive statistics for the number of microplastic particles found per gram of tissue in P. subtriangulata at the different sampling locations.*

ANOVA				
Source of Variation	*df*	*F*	*P-value*	*F crit*
Between Groups	1	28.539	0.6	4.494
Within Groups	16			

3.2.4 A comparison of selected sites between 2020 and 2021 of bioaccumulation in *M. liliana* and *A. stutchburyi*

There has been an increase in microplastic particles found in *M. liliana* and *A. stutchburyi* at Omokoroa (Fig. 12). No particles were extracted in 2020, but 13 particles were found in *M. liliana* and 8 particles in *A. stutchburyi* in 2021 (Fig. 12). No particles were found in *A. stutchburyi* at Otūmoetai in 2020, however 1 particle was extracted in 2021 (Fig. 12). The levels of microplastic pollution in both *M. liliana* and *A. stutchburyi* remained the same at Tuapiro Point Estuary and Ongare Point (Fig. 12).

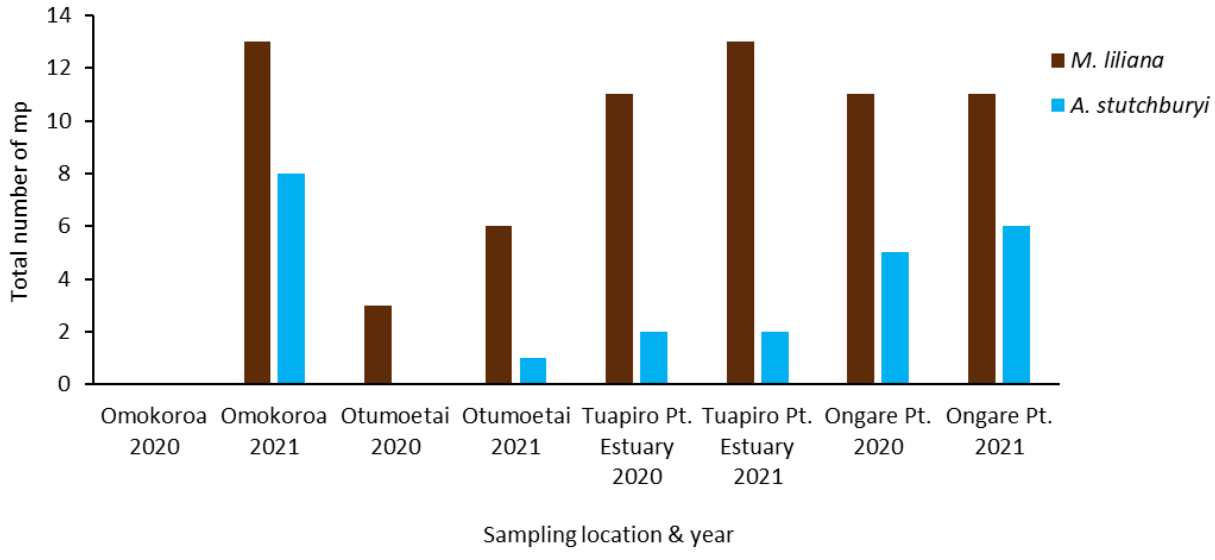

Figure 12. *The total number of microplastic particles extrapolated in 2020 and 2021 at each sampling location within the Tauranga Harbour and eastern coastline.*

3.2.5 Microplastic classification of bioaccumulation in bivalves

The greatest percentage of fragments was extracted in *M. liliana* (80%), with 45% fragments found in *A. stutchburyi* and 48% in *P. subtriangulata* (Table 10). Microplastic films were only found in small numbers in *M. liliana* (3%), *A. stutchburyi* (5%) and none in *P. subtriangulata* (Table 10). Microplastic fibres in *M. liliana* encompassed 17 %, 50% in *A. stutchburyi* and 52% in *P. subtriangulata* (Table 10).

The greatest number of fragments in *M. liliana* were enumerated at Rangataua Bay (16 particles), with high numbers of fragments also found at Omokoroa (11 particles), Tuapiro Point Estuary (13 particles), Little Waihi (11 particles) and Ōhiwa Harbour site 1 (11 particles) (Table 10). Furthermore, the greatest number of microplastic fibres in *M. liliana* were enumerated at Rangataua Bay (7 particles) (Table 10). Microplastic films were present in *M. liliana* at four locations; Ongare Point, Waimapu (Grace Road), Otumoetai and Omokoroa with 1 particle found at each location (Table 10).

The greatest number of fragments in *A. stutchburyi* were enumerated at Rangataua Bay (8 particles) (Table 10). Furthermore, the greatest number of microplastic fibres in *A. stutchburyi* were enumerated at Ōhiwa Harbour site 2 (Kutarere) with 7 particles found (Table 10). Microplastic films were only found at Waipapa (3 particles) (Table 10).

The greatest number of fragments isolated in *P. subtriangulata* were found at Papamoa Domain (Sunbrae Ave), Matakana Island site 2 (sewage outfall) and the inner harbour at Matakana Island, with 5 particles enumerated at each of those locations (Table 10). Furthermore, the greatest number of microplastic fibres in *P. subtriangulata* were enumerated at Matakana Island sewage outfall and Waihi Beach site 2, with 6 particles counted at each location (Table 10). No microplastic films were isolated in *P. subtriangulata*.

Table 10. *The percentage of microplastic particles extrapolated for each category (fragments, fibres, and films) from A) A. stutchburyi, B) M. liliana and C) P. subtriangulata at each location within Tauranga Harbour and the eastern coast.*

	M. liliana			***A. stutchburyi***			***P. subtriangulata***		
Location	**Fragments**	**Films**	**Fibres**	**Fragments**	**Films**	**Fibres**	**Fragments**	**Films**	**Fibres**
Ongare Point	7	1	3	5	0	1			
Waimapu (Grace Road)	2	1	3						
Welcome Bay (Rotary Park)	0	0	3	0	0	1			
Pahoia 1	8	0	0						
Pahoia 2	7	0	1						
Waikareao Estuary	0	0	2	0	0	0			
Omokoroa	11	1	1	7	0	1			
Tuapiro Point Beach	7	0	2	1	0	0			
Tuapiro Point Estuary	13	0	0	0	0	2			
Karewa Parade							3	0	2
Papamoa Domain (Sunbrae Ave)							5	0	0
Papamoa Domain (boat ramp)							2	0	3
Maketu Estuary	9	0	1	3	0	6			
Little Waihi Estuary	11	0	0	1	0	4			
Otūmoetai	4	1	1	0	0	1			
Katikati	3	0	0						
Waipapa	6	0	3	0	3	0			
Pios Beach	9	0	0	1	0	3			
Rangataua Bay	16	0	7	8	0	2			
Ōhiwa Harbour 1 (Wainui)	11	0	0	0	0	1			
Ōhiwa Harbour 2 (Kutarere)	3	0	0	1	0	7			
Matakana Island 1 (South)							1	0	0
Matakana Island 2 (sewage outfall)							5	0	6
Matakana Island 3 (North)	0	0	0	0	0	1	0	0	3
Matakana Island 4	5	0	2						
Matakana Island (inner harbour)							5	0	5
Matahui	2	0	0						
Waihi Beach 1							2	0	3
Waihi Beach 2							3	0	6
Total # of particles	**134**	**4**	**29**	**27**	**3**	**30**	**26**	**0**	**28**
Percentage	**80**	**3**	**17**	**45**	**5**	**50**	**48**	**0**	**52**

The bivalves were measured, and seven size groups identified. The morphotypes of microplastic particles were calculated for each size group. The greatest proportion of fragments, films and fibres occurred in *M. liliana* measuring between 20 and 30 mm in size (Fig. 13). Furthermore, a proportion of fibres and fragments were also identified in *M. liliana* measuring between 30 and 40mm (Fig.13). The greatest amount of microplastic particles measured in *A. stutchburyi* were in the 10 to 20mm size range, with some in the 20 to 30mm and others in the 50 to 60mm range (Fig. 13). The greatest proportion of microplastic fibres in *P. subtriangulata* sizes ranging between 40 and 50mm and a small percentage between 30 and 40mm (Fig. 13). No microplastic films were present in *P. subtriangulata* (Fig. 13).

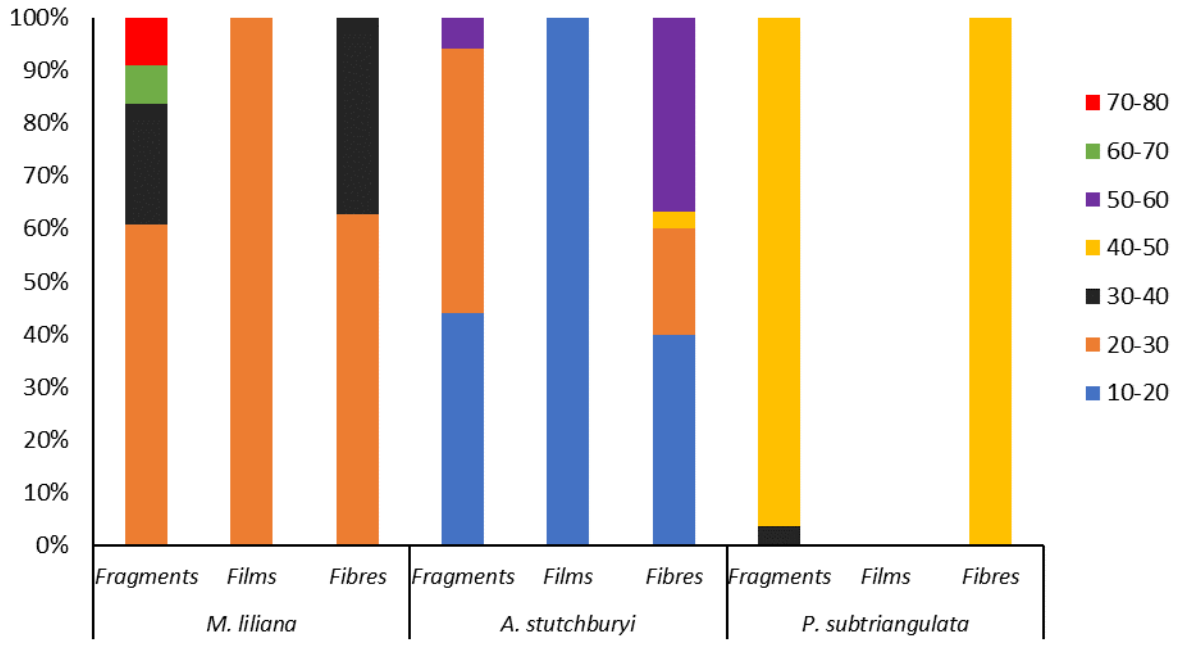

Figure 13. *Proportion of microplastic particles found in different size classes for each morphotype (fragments, films, and fibres) isolated in the tissue of the three bivalve species.*

3.2.6 Fourier Transform Infrared Spectroscopy (FTIR) – bivalve bioaccumulation

The FTIR results indicated high bioaccumulation rates (34 %) of polyester, polyamide (27%) (nylon), and polyethylene (25%) (Fig. 14). Furthermore, small proportions of inorganics (5%) and polyvinylchloride (9%) were also extrapolated (Fig. 14).

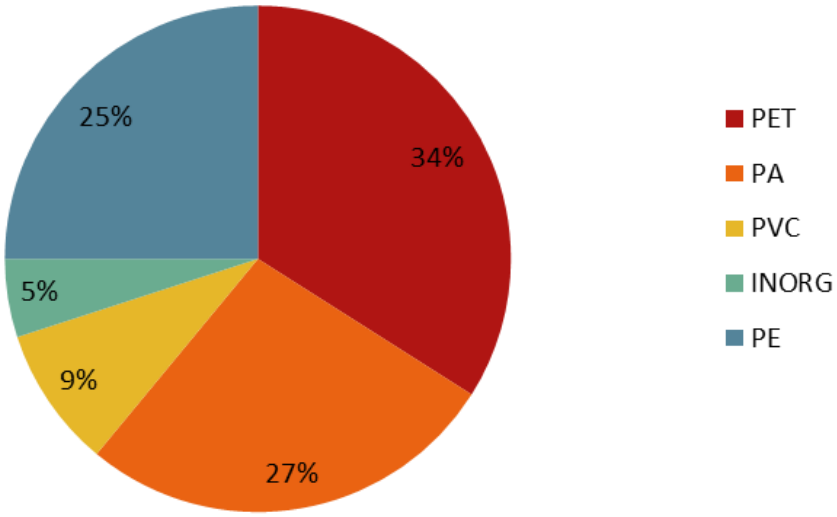

Figure 14. *Fourier transform infrared spectroscopy results of microplastics found in bivalves; PET is polyester (including polyethylene terephthalate), PA is polyamide/nylon, PVC is polyvinylchloride, Inorg is inorganics (calcium carbonate, magnesium silicate and silica) and PE is polyethylene.*

Chapter 4

Discussion

4.1 Accumulation Rates in Marine Sediment

Microplastics were identified at all sites within the Tauranga Harbour and the eastern coastline ranging from low to medium sediment concentrations with some hotspots of microplastic accumulation at sites near populated and sewage outfall areas. These results correlate with previous research conducted in New Zealand (Canterbury and Auckland), and international research (South Korea and East Frisian Islands), using similar sampling and processing protocols (Bridson et al., 2020; Clunies-Ross et al., 2016; Harris, 2020; Liebezeit & Dubaish, 2012). Microplastic particles are spatially and temporally widespread in sediment in the marine environment, with abundance being dependant on several factors, such as river outflows, land use, littoral and longshore drift, hydrodynamics within estuarine and harbour areas, wind patterns and oceanic currents (Cole et al., 2011; Hale et al., 2020; Ng & Obbard, 2006).

The Tauranga Harbour and eastern coastline are less populous than Canterbury and Auckland, however, similarly high concentrations of microplastic particles were estimated. Compared to international studies, lower concentrations of microplastic particles were extrapolated from the sediment in this study and the rest of New Zealand (Bridson et al., 2020; Clunies-Ross et al., 2016; Harris, 2020; Ng & Obbard, 2006). Only two other studies have been conducted in other parts of New Zealand which found lower levels of microplastic particles (0 – 29 kg^{-1} in Auckland & 0 – 45.4 kg^{-1} in Canterbury). This was surprising given that Tauranga Harbour is less populated than Auckland and Canterbury.

Earlier studies conducted globally, identified microplastic hotspots and high concentrations of accumulation in sediment were found in the East Frisian Islands (0 – 36 kg $^{-1}$) (Liebezeit & Dubaish, 2012), Belgium (53 – 390 kg $^{-1}$) (Claessens et al., 2011) and one of the highest concentrations in Venice (672 – 2175 kg $^{-1}$) (Vianello et al., 2013). A literature review identified East Asia as a microplastic hotspot with the highest number of microplastic accumulation in sediment globally (W. C. Li, 2018). A study conducted in the Hauts-de-France region showed microplastic abundances ranging from 23.4 to 69.3 per kg $^{-1}$ (DW) (Doyen et al., 2019). There was no difference found between locations and tidal zones in the Hauts-de-France study, however, this study shows similarity regarding tidal zones but not locations (Doyen et al., 2019). There was a difference between the numbers of microplastic particles per m² and per kg-1 (DW) extrapolated at the various locations, however, there was no significant difference between intertidal and high-tide zones. In this research, microplastic accumulation in sediment was higher in certain locations, such as around sewage outfalls and highly populous areas. Sediment collected at intertidal zones in Scapa Flow, Orkney, employed similar methodologies to this study, and showed mean concentrations of 730 and 2300 particles per kg^{-1} (DW), which are higher than the concentrations found in the Bay of Plenty, New Zealand (Blumenröder et al., 2017). Research conducted in internationally remote areas such as the Artic and Antarctica demonstrated low concentrations of microplastics present in sediment, due to being regions least affected by anthropogenic pressures (Tirelli et al., 2020). Microplastic particles were discovered in deep ocean sediment in the Mariana Trench with concentrations between 200 – 2200 particles per kg $^{-1}$ (DW) (Peng et al., 2018).

Internationally there is evidence of increasing microplastic accumulation in sediments over time. For example, sediment core samples at different depths were investigated in Tasmania, Australia to determine microplastic accumulation in sediment over time, which demonstrated

a more prolific distribution in the upper sediments (new depositions) (Willis et al., 2017). This study provides support for microplastics as an emerging contaminant with the introduction and widespread use of plastics. Furthermore, it supports our findings of high microplastic accumulation in sediment, with core samples we collected at a depth of five centimetres. Mangroves accumulate high amounts of sediment and as a result microplastic particles, thus, sediment at mangrove forests are considered to be microplastic sinks (Martin et al., 2020). Furthermore, since an upsurge in plastic manufacturing in the 1950's, an exponential rise is observed in plastic burial rates in mangrove forest sediment (Martin et al., 2020).

It is expected that a higher abundance of microplastic particles would be evident in the lower as opposed to the upper areas of the Bay of Plenty catchment, due to different land use. The upper area of the catchment consists mostly of agriculture and some pastoral land, whereas the lower areas are urbanised. Increased concentrations of particles were found around sewage outfalls and populous areas. Urbanisation results in an increase in anthropogenic pressure on the environment with several point and non-point sources of microplastic pollution which is ubiquitous in the marine environment (Auta et al., 2017; Besley et al., 2017; Hale et al., 2020).

Increased concentrations of microplastics in marine sediment occur in populous areas due to factors such as plastic disposal in terrestrial systems, wastewater treatment, paint and textile fibres derived from washing (Hale et al., 2020; Rochman, 2018; Rochman et al., 2015). Microplastics are discharged into the marine environment through storm water, rivers, weather events, atmospheric transport and distributed by oceanic currents (Hale et al., 2020; Horton & Dixon, 2018; Rochman, 2018; Rochman et al., 2015). Research in Southern California implies that wastewater treatment plants encompass significant point sources of microplastic

pollution to the marine environment (Carr et al., 2016). Several sources and sinks were identified such as wastewater treatment plants and weirs (Horton & Dixon, 2018; Mani et al., 2015). A study by Murphy et al. in 2016 described the fate of microplastics during wastewater treatment, and discovered that the wastewater treatment plant contributed to 65 million microplastic particles into the receiving water (Murphy et al., 2016). A study in the Rhine-Ruhr metropolitan area exuded diverse concentrations of microplastic pollution from wastewater effluent throughout the river, a mean of 3.9 million particles per km^{-2} were extrapolated (Mani et al., 2015).

Pathways for microplastic particles to enter the Tauranga / Bay of Plenty study site include rivers, wastewater outlets, recreational activities, and urbanisation. In this study we found that areas next to rivers, wastewater outflows and populated areas had higher microplastic accumulation. The Ōhiwa Harbour System demonstrated slightly lower numbers, of microplastic pollution compared to the Tauranga Harbour System. There was a small variance in microplastic pollution between these two sites which is concerning as Tauranga Harbour is more populous than Ōhiwa Harbour, and theoretically should demonstrate higher microplastic pollution than the latter. However, aquaculture activities (notably an oyster farm located in Ōhiwa Harbour), as well as harbour hydrodynamics could be potential sources of plastic pollution in Ōhiwa Harbour. There was a significant difference in microplastic pollution between Ōhiwa Harbour, Tauranga Harbour, and the eastern coastline, with higher numbers of microplastics extracted at the eastern coastline. However, there was no difference between the hightide and intertidal zones at the sampling locations.

Extremely high numbers of microplastic particles (11087.9 m^2) were found in two locations. Firstly, at Karewa Parade, located in Papamoa East, which could be a consequence from the

Rena disaster that occurred in October 2011, when the RV Rena grounded on the Astrolabe reef (Otaiti) (Faaui et al., 2017; McLean, 2018; Schiel et al., 2016). The Rena disaster was classified as New Zealand's worse maritime disaster with oil spills and the release of debris from hazardous commodities (Battershill et al., 2016; McLean, 2018; Schiel et al., 2016). An abundance of plastic microbeads were scattered across the eastern shoreline as a result of this disaster. Secondly, high numbers of microplastic particles were extracted at the intertidal zone of the Omanu Sewage Outfall and intertidal zone at Papamoa Domain. The increased number at the Omanu sewage outfall could be the effect of point source pollution due to the sewage outfall. However, investigating the hydrodynamics and sedimentary characteristics of this area will prove beneficial to further understand the increased accumulation of microplastic particles in the intertidal area at Omanu. The high numbers found at Papamoa Domain could be attributed to various non-point sources of pollution such as the Rena disaster, fishing, and recreational activities, as this is a very popular beach. Furthermore, high numbers of microplastic particles were also measured at the intertidal zone at Ohope Beach, which could be due to ocean currents, and Ohope is a popular beach for fishing and numerous recreational activities.

The lowest microplastic levels per m^2 were observed in the intertidal zone at Matakana Island (site 1), which are at the southern end of the island. All the sampling locations at Matakana Island were indicative of lower numbers of microplastic particles in comparison to the other sampling areas. Matakana Island is considered pristine as it is not highly populous and not many people visit the island. Agricultural, forestry and horticulture encompass some of the land-use on the island, however, these activities are highly regulated and exercised in a sustainable manner. The area in close proximity to the sewage outfall were also indicative of

low numbers of pollution, possibly due to dominant currents that transport the particles away from the island.

Microplastic distribution across beaches and estuaries is expected to be irregular (Claessens et al., 2013; Clunies-Ross et al., 2016; Liebezeit & Dubaish, 2012; Vianello et al., 2013). Recent evidence from literature suggests that it is highly unlikely that there will be no spatial variability when sampling for microplastics (Claessens et al., 2011; Clunies-Ross et al., 2016; Liebezeit & Dubaish, 2012; Vianello et al., 2013). This could be a possible explanation for the variability of microplastic concentrations between the different sampling locations. High variability was expected based on findings from other studies. Due to both pathways of microplastics entering estuarine systems as well as hydrodynamics of an area that then drive where microplastics are likely to be deposited. This study found, as expected, high spatial variability in deposition between locations. This is likely due to wave action and sediment sorting, contributing to increased accumulation of microplastic particles at the high tide as well as the intertidal zones at the different locations.

The first study describing the distribution of micro “granules” on New Zealand beaches were conducted in 1978 by Gregory, which found particles widely distributed on the New Zealand shore, with increased numbers around Auckland, Christchurch and Wellington (Gregory, 1978). The high recovery rate of microplastics discovered in this study could be explained by several factors, such as point- and non-point sources of pollution. Microplastics have been found to be abundant throughout benthic sediment in both marine and freshwater ecosystems (Bridson et al., 2020; H. K. Imhof et al., 2013; Van Cauwenberghe et al., 2013; Willis et al., 2017). It is widely accepted that sediment are most prevalent as sinks of microplastic pollution to the marine environment (Boucher & Friot, 2017; Claessens et al.,

2013; Green et al., 2016; Van Cauwenberghe et al., 2013). Spatial and temporal distribution patterns of microplastic particles in Wellington New Zealand further supports beach sediment as significant microplastic sinks, as well as influenced by environmental factors such as erosion and wind patterns (Shannon, 2020).

Tidal cycles might also have a significant effect on microplastic deposition in beach substrate (Blumenröder et al., 2017; Clunies-Ross et al., 2016; Sterl et al., 2020). Microplastic particles can inertly move through the environment and have the ability to float, suspend or sink due to polymer density (Besley et al., 2017; Blair et al., 2019; Boucher & Friot, 2017; Clunies-Ross et al., 2016). Longshore drift, tidal cycles and ocean currents create a dynamic shift of microplastic particles from one area to another (Kane & Clare, 2019; Sterl, Delandmeter & van Sebille, 2020; Zhang, 2017). Ekman drift and Stokes drift principles describe surface drifting of buoyant particles through wind and wave action and Langmuir Circulation explains the vertical mixing of microplastic particles through the subsurface sediment (Kane & Clare, 2019; Sterl, Delandmeter & van Sebille, 2020; Zhang, 2017).

4.1.1 Microplastic Morphotypes Identified in the Sediment

Microplastic particles are categorized into three main morphotypes; fibres, films and fragments (Besley et al., 2017; Boucher & Friot, 2017; Dris et al., 2016). The sizes measured for all particles ranged between 150 µm – 5 mm. Larger sized particles, showed the highest proportion measured for each polymer morphotype. The greatest number of particles observed were microplastic fibres, followed by fragments and the lowest percentage extrapolated belonged to microplastic films. These results are similar to other studies in New Zealand (Canterbury and Auckland regions) which found microplastic fibres to encompass the greatest proportion of total particles extrapolated (Bridson et al., 2020; Clunies-Ross et al.,

2016). Most of the particles were clear and opaque, which is consistent with a literature review, which similarly discovered the bulk of particles appearing white, transparent, and opaque (Hidalgo-Ruz et al., 2012). Microplastics extracted from beaches at Qingdao, China, were primarily microplastic fibres (> 97%) which were indicative of industrial development, as well as hydrodynamic and geographical conditions (Pervez et al., 2020). Although the study in China demonstrated a higher proportion of fibres in marine sediment in comparison to this research, it validates the high percentage of fibres found in the Bay of Plenty area.

High numbers of microplastic particles were extracted around populous areas and sewage outfalls as previously mentioned. Wastewater treatment plants are a possible point source of pollution to the environment, as demonstrated by two novel studies conducted in the UK and USA (Blair et al., 2019; Murphy et al., 2016). Polypropylene fibres (67%) were the most abundant particles being discharged to the recipient water body in the UK (Blair et al., 2019). The USA study demonstrates a release of 65 million microplastic particles daily to the receiving water (Murphy et al., 2016). Furthermore, significant numbers of fibres (63%) were extracted from sewage sludge in China, confirming sewage sludge from wastewater treatment plants as an important source of microplastic pollution to the environment (Li et al., 2018).

Turbidity currents are a key process transporting terrestrial sediment containing microplastic fibres and fragments to deep ocean trenches and the seafloor (Pohl et al., 2020). Fibres are equivalently distributed in the turbidity current, whereas fragments are concentrated at the base of the current (Pohl et al., 2020). However, a trend was noted, a higher abundance of microplastic fibres accumulated in the sediment compared to plastic fragments (Pohl et al., 2020). This ambiguity is explained by a depositional process whereby fibres are trapped

between sediment particles, removed from suspension, and settle into benthic sediments (Pohl et al., 2020). Furthermore, this study highlighted the seafloor as an important sink for oceanic microplastic pollution (Pohl et al., 2020). The seafloor as a potential sink, could have a fundamental effect on microplastic particles being transported and deposited in estuarine and nearshore environments as a result of tidal currents (Harris, 2020; Pohl et al., 2020; Van Cauwenberghe et al., 2013).

4.2 Bioaccumulation in Bivalves

Increased numbers of microplastic particles were found in the deposit feeding *M. liliana* compared to the two-filter feeding species; *A. stutchburyi* and *P. subtriangulata*. This finding could be explained by their different feeding modes in the environment. *M. liliana* is a deposit feeder, ingesting large amounts of sediment to extract food particles, whereas *A. stutchburyi* and *P. subtriangulata* filter feeds, extracting food particles from the water column (Ivar do Sul & Costa, 2014; Thompson et al., 2004). First, pathways for microplastic bioaccumulation in bivalves are discussed before considering potential sources contributing to microplastic input into bivalve habitats.

Several studies investigated the ingestion and retention of microplastics in shellfish and found that these animals likely ingest microplastics similar in size to their natural food sources (Ding et al., 2020; Q. Li et al., 2021). Previous studies identified three primary pathways by which bivalves acquire microplastic particles: synthesis, adherence, and ingestion, with ingestion the likely means by which they take up microplastics (Baroja et al., 2021; Q. Li et al., 2021; Phuong et al., 2018). Furthermore, studies noted the adherence of particles to other organs, such as gills and mantle of mussels, concurrently with being present in the

gastrointestinal tract (Ding et al., 2020; Q. Li et al., 2021). This provides evidence of various pathways for microplastic particles to bioaccumulate in bivalves.

Local and international research highlight the presence of microplastic particles in the marine environment, which directly expose biota to probable ingestion of these particles (Dris et al., 2016; Green et al., 2016; Ng & Obbard, 2006). The particles can be directly or indirectly consumed by feeding on bottom trophic prey species (Farrell & Nelson, 2013; Wang et al., 2015). Research noted the presence of microplastic particles in several species of bivalves, such as oysters, mussels and clams (Cho et al., 2019; Covernton et al., 2019; Dawson et al., 2021). Bivalves contribute a pivotal role to ecosystem functioning which could be disrupted due to microplastic exposure (Adkins et al., 2014; Baroja et al., 2021; Bour et al., 2018). The presence of microplastics have direct and indirect consequential effects on bivalves in the environment (Bowley et al., 2021; Cho et al., 2021). Direct effects include reproduction defects, growth inhibition, filtration functioning disrupted, lack of feeding and digestion proficiency, whereas, indirect effects include destabilisation of food sources, habitat alteration and persistent organic pollutants being ingested (Rochman et al., 2015; Scanes et al., 2019; Van Cauwenberghe & Janssen, 2014). Furthermore, ingesting microplastic particles can cause lacerations, malnutrition, and infection in all bivalve species (Baroja et al., 2021; Zhang et al., 2020). Research have noted the vertical transfer of microplastic particles to the highest tropic levels in the food chain (Ding et al., 2020; Green et al., 2016; Halstead et al., 2018; Wang et al., 2015).

A recent study demonstrated the ingestion and presence of microplastics of < 2 µm in *Saccostrea glomerata* (Sydney Rock Oyster) (Scanes et al., 2019). Furthermore, microplastic particles were discovered in the haemolymph of *S. glomerata*, which are likely due to

phagocytosis (Jahan et al., 2019; Scanes et al., 2019). This provides evidence of microplastic particles which are prevalent in *S. glomerata's* environment being ingested (Jahan et al., 2019b; Scanes et al., 2019). Microplastic particles are similar in size and resemble planktonic food of filter feeding bivalves (J. Li et al., 2015; Lopez & Levinton, 1987; Scanes et al., 2019). Enzymatic pathways are needed to break down microplastic particles, which lack in biota such as *S. glomerata*, thus allowing translocation through the cell membrane where the particles are lodged into the tissue (Phuong et al., 2018; Scanes et al., 2019; Zhang et al., 2020).

Filter feeders may also feed unintentionally on microplastics, as the particles are buoyant and easily transported in the water column (Ivar do Sul & Costa, 2014; Prinz & Korez, 2019; Thompson et al., 2004). Microplastic particles have an inherent electric charge, resulting in them adhering to equal yet opposite charged particles in the natural environment (Ivar do Sul & Costa, 2014; Prinz & Korez, 2019; Thompson et al., 2004). Plastic particles hold electrical charge when moving through air or water, due to motive force, potentially influencing bivalve ingestion (Ivar do Sul & Costa, 2014; Prinz & Korez, 2019; Thompson et al., 2004). One of the first studies on fish and shellfish, showed the presence of anthropogenic debris in the gastrointestinal tract in a significant percentage of the species sampled (Rochman et al., 2015). In addition, microplastics are linked to dangerous chemical substances which evidently are bioavailable to seabirds (Rochman et al., 2015).

Aquaculture recently became a popular industry, due to alternative food sources required with the exponential growth of the global population (Covernton et al., 2019). However, aquaculture is another possible contributor of microplastic pollution to the marine environment that necessitates consideration. Shellfish aquaculture ventures use vast amounts of plastic products for cultivation and predator exclusion within the environment

(Covernton et al., 2019). Research in Canada investigated the presence of microplastics in Manila clams (*Venerupis phillippinarum*) and Pacific oysters (*Crassostrea gigas*) (Covernton et al., 2019). Samples were collected from both aquaculture sites and natural populations in close proximity to each other to allow for comparison (Covernton et al., 2019). The study noted a negligible increase in microplastic particles in oysters and clams at sites containing anti-predator nets, however, upon closer investigation with FTIR spectroscopy, most particles were nylon and polyester which are polymers rarely used in the aquaculture industry (Covernton et al., 2019). Although, aquaculture practices are mostly located in the open ocean, and this study focused on benthic species, the evidence could prove valuable when evaluating the effects of microplastic particle ingestion relating to various feeding modes. In this case the oysters and clams are both filter feeders.

Microplastics are a possible threat to the marine ecosystem in New Zealand, however not much data is available on the effects and abundance of microplastic particles in marine biota (Webb et al., 2019). *Perna canaliculus* (green-lipped mussel) is a significantly important aquaculture target species in New Zealand (Webb et al., 2019). A pilot study in 2019 on green-lipped mussels in New Zealand, found microplastics present in *P. canaliculus* at six of the nine locations sampled (Webb et al., 2019). Microplastic abundance varied between 0 to 0.48 particles per gram of tissue (Webb et al., 2019). Green-lipped mussels sampled at Mount Maunganui had similar microplastic bioaccumulation rates per gram of tissue compared to the filter-feeding bivalves in this study (Webb et al., 2019). A greater abundance of microplastic particles per gram of tissue were present in the deposit feeding *M. liliana* in this study, compared to the filter feeding *P. canaliculus*. *P canaliculus* showed slightly lower microplastic abundance than the filter feeding *A. stutchburyi*. This could be explained by the different localities at which the two species are found at in the marine environment, *P*

canaliculus was sampled at the coast, whereas *A. stutchburyi* is an estuarine species (Adkins et al., 2014; Schenone & Thrush, 2020; Webb et al., 2019). The coastal filter feeding species *P. subtriangulata* demonstrated a similar range of microplastic particle abundance per gram of tissue compared to *P canaliculus*. The similarity in microplastic abundance in these two species are expected as they are both filter feeding within the same environment.

4.2.1 Microplastic Morphotypes Identified in Bivalves

The greatest percentage of total microplastic particles extracted, was categorised as fragments, with the greatest bioaccumulation identified in *M. liliana*. Microplastic films were only found in small numbers in all three species. A greater concentration of microplastic fibres were extracted from *A. stutchburyi* and *P. subtriangulata* than from *M. liliana.* These findings compare to recent international studies (Hermabessiere et al., 2019; Phuong et al., 2018; Wakkaf et al., 2020). The high abundance of microplastic fibres found in the two filter feeding species (*A. stutchburyi* & *P. subtriangulata*) are equivalent to the high accumulation of fibres found in the sedimentary environment in this research. The high accumulation of fibres in the direct environment of filter feeders could contribute to high ingestion rates (Meyhöfer, 1985; Phuong et al., 2018; Zhang et al., 2020). Previous research noted the prolonged persistence of microplastic fibres in the water column compared to plastic fragments which accumulate persistent organic pollutants and sink to sediment (Cho et al., 2021; Halstead et al., 2018). This behaviour of microplastic particles in the environment possibly explains the abundant presence of fibres in filter feeding biota which predominantly filter their food from the water column. A study conducted on the eastern shore of Halifax Harbour, Nova Scotia by Mathalon & Hill in 2014, noticed microfibres in cultivated and wild populations of *Mytilus edulis* (blue mussel). However, microplastic bioaccumulation in farmed mussels were higher than in wild populations (Mathalon & Hill, 2014). At the most polluted

site 128 fibres was discovered per mussel in the wild population compared to 178 in cultivated population (Mathalon & Hill, 2014).

The high abundance of plastic fragments in *M. liliana* could be explained by several factors. The volume and colour of microplastic fragments can add to the probability that marine biota will ingest them (Clunies-Ross, 2016; Van Cauwenberghe et al., 2013). The large quantity of microplastic particles found throughout our sampling locations may have serious consequences for marine biota (Clunies-Ross, 2016). A recent literature review showed that feeding efficiencies and nutritional health of marine organisms are reduced by microplastic ingestion (Prinz & Korez, 2019). Depleted energy reserves, reduced growth, reproduction, maturity, and somatic cell maintenance are affected (Prinz & Korez, 2019). Bivalves offer valuable ecosystem services such as, water quality control through their immense filtering capabilities and wide spatial topographical distribution (Wang et al., 2015). Mussels could be utilized as valuable bioindicators of microplastic pollution levels in the marine environment as discovered by a study conducted along the Korean coast (Cho et al., 2021).

4.2.2 Microplastic Morphotypes in Different Bivalve Size Classes

A study in New Zealand investigated microplastic ingestion in different sized, green-lipped mussels and found that there was no relationship between size and the presence of microplastic particles in *P. canaliculus* (Webb et al., 2019). International studies took microplastic size into consideration and not bivalve size classes (Cho et al., 2021; J. Li et al., 2015; Zhang et al., 2020). However, in this study bivalves of various sizes for all three species were collected, and microplastic particles extracted. In *M. liliana* the highest proportion of fragments, films and fibres were found in individuals measuring between 20 and 30mm, with a smaller proportion of fragments and fibres extracted in individuals between 30 and 40mm

in size. Smaller individuals of *A. stutchburyi*, between 10 and 20mm in size, showed the greatest proportion of fibres, films and fragments. Individuals of *P. subtriangulata*, measuring between 40 and 50mm encompassed the greatest percentage of fragments and fibres. Both, size, and shape of microplastic particles need to be taken into consideration when evaluating microplastic particle ingestion rates within different sized bivalves. Particles greater than 100µm will be unlikely ingested due to anatomical limitations presented in the bivalves (Ward et al., 2019). The focus of our study was only to determine the presence of microplastic particles in the different bivalve species, a yes/no hypothesis, therefore not all the plastic particles were measured. Bivalve sizes are unlikely to exert an effect on microplastic ingestion rates, due to the great variation of particles extracted across the different size classes in this study, as well as no proven relationship between mussel size and ingestion rates in green-lipped mussels (Webb et al., 2019).

4.3 Behaviour of Microplastic Particles in the Environment

Physical properties, such as size, density, and shape of microplastic particles could be compared to sediment grain properties, which could explain the movement, resuspension, and accumulation of microplastics in the environment (Isachenko & Chubarenko, 2021). Sedimentary traits and microplastic size directly affect the initiation of movement of certain microplastic particles (Isachenko & Chubarenko, 2021). High accumulation zones of microplastic particles were observed with an increase in sediment roughness, thus an intrinsic relationship occur between plastic particles and sediment grains, which are explanatory of the spatial variability of microplastic particles in sedimentary environments (Isachenko & Chubarenko, 2021). The estuarine substrate in our study, were mostly mudflats and finer sediment grains, whereas the sediment at the coast were larger grains and well sorted which

explains in part the greater accumulation of microplastic particles in the sediment on the outer coastal areas compared to the estuarine environments. Furthermore, it is also explained by 1) the source of microplastics, 2) hydrodynamics that move around the microplastics and then 3) environmental factors such as grain size.

4.4 Polymer Types Extracted with FTIR Spectroscopy

4.4.1 Polymers enumerated in Sediment

The FTIR results displayed high accumulation rates (40%) of cellulose and regenerated cellulose (cotton, rayon fibres, or cellophane) in the sediment. Furthermore, 37% inorganics (calcium carbonate, magnesium silicate and silica) were noted, as well as 13% polyvinylchloride and 10% polyamide (nylon). No polyurethane was enumerated; however, it could have been overlooked when subsets was selected as it shows similar properties under the microscope compared to other polymers but also not as prevalent in the environment (Halstead et al., 2018; Lusher et al., 2014).

Cellophane (polyethylene) are also commonly found in studies conducted of sediment internationally and in New Zealand. Cellophane has been manufactured from regenerated cellulose since the 1930's and most commonly used in food packaging but also applied as a base in several industrial processes such as self-adhesive tapes, semi-permeable membranes, dialysis tubing and one of the most severe pollutants cigarette butts (Aziegbe, 2007; Gu et al., 1993). Cellophane is fully biodegradable and requires between 3–6 months to decompose (Aziegbe, 2007). An earlier study presented significant numbers of polyethylene in table salt from China (Yang et al., 2015). Cellophane has wide applications in a variety of commercial products and that might be explanatory as to the anomalously high proportion observed in

the environment. It could be concluded that cellophane pollution in the environment originates from multiple sources.

Rayon is commonly used as a textile fibre because it has properties resembling silk but also used for surgical products (Halstead et al., 2018; Lusher et al., 2014). Rayon is manufactured from wood pulp, which is classified as a natural material, however carbon disulphide is a toxic substance used during the engineering process (Halstead et al., 2018; Lusher et al., 2014). The more hydrophobic the rayon fibre is, the slower it biodegrades in the environment. Therefore, it could take between 20–200 years to fully degrade (Halstead et al., 2018; Lusher et al., 2014). Previous research depicted that rayon totals 56.9 % of fibres found in deep oceanic expanses (Halstead et al., 2018). Washing machine and wastewater discharges could be responsible for the high levels of microplastic fibres observed throughout sampling locations. Tauranga Harbour and eastern coastline are popular recreational locations which could add to the pollution levels of microplastic fibres.

Polyvinyl chloride (PVC) is also commonly found in research literature. PVC is manufactured from chlorine and ethylene extracted from oil, which undergo the process of polymerisation with the end product being polyvinal chloride resin (Braun, 2001; Brennecke et al., 2016; Ziccardi et al., 2016). PVC is widely applied in industry such as pipes, insulation on electric cables, construction, water resistant clothing and flooring (Brennecke et al., 2016; Braun, 2004). Ironically, PVC is one of the most toxic compounds but is used in the healthcare industry as phlebotomy tubes, catheters and in blood transfusions (Braun, 2004). Microplastics derived from PVC persist for decades in the environment and is only successfully broken down by the bacterium *Aspergillus fumigatus*, which is found in terrestrial soil ecosystems and thus have little to no decomposing impact in marine ecosystems (Brennecke

et al., 2016; Braun, 2004; Ziccardi et al., 2016). Furthermore, PVC absorb persistent organic pollutants (POPs) and are then ingested by biota in the environment (Brennecke et al., 2016; Braun, 2004; Ziccardi et al., 2016). The presence of PVC in the environment could be attributed to the wide use of the material but mostly in water resistant clothing such as wet suits and washing effluent.

Nylon is a generic term describing a group of synthetic polymers consisting of polyamides with a silk-like appearance, and usually manufactured as a fibre used in microfilaments (Bulte et al., 1993; Mckeen, 2017; *Nylon | History, Properties, Uses, & Facts | Britannica*, n.d.). DuPont engineers created polyamide in the 1930's and it is widely used across several industries, including manufacturing of rope and stockings (Bulte et al., 1993; Mckeen, 2017). Additives combined with polyamide result in various industrial applications such as apparel, flooring, rubber reinforcement, car parts and electrical equipment (Hill, 2005; Mckeen, 2017). Food packaging is regarded as a microfilm with the primary constituent being polyamide (Bulte et al., 1993; Hill, 2005; Mckeen, 2017). Nylon is not biodegradable, and sheds fibres which enter the environment every time a piece of clothing is washed (Hill, 2005; Mckeen, 2017). Nylon will persist indefinitely in the environment, with no means of being broken down, which could contribute to severe effects on biota.

Polyurethane is the least commonly found microplastic particle in the environment (Russell et al., 2011). Mixing two or more fluid flows produces polyurethane and are called a polyurethane system (Browne et al., 2007, 2010; Russell et al., 2011). Polyurethane is a sponge-like cushioning material used in furnishings, carpet underlay, automotive interiors, home insulation and boat parts (Dris et al., 2016; Murphy et al., 2016; Russell et al., 2011). Polyurethane persists for more than two years in the environment before it degrades (Dris et

al., 2016; Murphy et al., 2016; Russell et al., 2011). A recent study described the ability of endophytic fungi to biodegrade polyurethane which may prove beneficial in the long term to mitigate polyurethane pollution in the environment (Russel et al., 2011). Although, polyurethane only comprises a small proportion of the overall microplastics found, it has been documented to have significant effects on biota in marine ecosystems (Russel et al., 2011).

4.4.2 Polymers enumerated in Bivalves

The FTIR results indicated high bioaccumulation rates of polyester (PET), including polyethylene terephthalate), polyamide (nylon), and polyethylene (PE). Furthermore, small proportions of inorganics and polyvinylchloride (PVC) were extrapolated. Similar polymer types were extracted in both the bivalves and sediment apart from polyester and polyethylene terephthalate. Polyester and polyethylene terephthalate was the only group found in bivalve tissue but not noted in the sediment samples. A subset of polyester in the sediment samples was possibly not selected for FTIR- spectroscopy due to a close resemblance to other fibrous particles.

Polyester, also known as polyethylene terephthalate, is the most frequently found microplastic in the environment and is a colorless resin (Datye et al., 1984; Stoll et al., 2019). Polyester encompasses a wide scope of uses, such as plastic bottles, yarn, fruit packaging and microfiber towels (Datye et al., 1984; Stoll et al., 2019). Polyester is characterized by intrinsic viscosity which comprises of long polymer chains. A study by Bollinger et al., in 2020, investigated the possibility of biodegrading polyethylene terephthalate, due to its frequency of occurrence in the environment. Enhancement of the enzymatic properties of the bacterium *Pseudomonas aestusnigri* was investigated, which resulted in the significant potential of this marine bacterium to biodegrade polyethylene terephthalate (Bollinger et al., 2020).

4.4.2 Brief Comparison of Polymers Found in Sediment and Bivalves

High numbers of polyethylene in both the sediment and bivalves were extrapolated. The increased presence of polyethylene in the direct environment of the bivalves could explain the elevated bioaccumulation in the tissue of all three species investigated in this study. Rayon was only evident in the sediment with no subset of plastics isolated from the bivalves appearing in this group. The occurrence of shellfish beds within the Bay of Plenty are spatially varied which could result in sediment samples taken at more locations as to where shellfish beds are present. Polyvinyl chloride was present in both sediment and bivalves, showing similar abundance. Again, this could be explained by the direct presence of the microplastic particles in the bivalve's environment, ingestion rates of bivalves could also explain the similar levels extrapolated. Polyamide (nylon) was present in the sediment as well as in the bivalves. The increased bioaccumulation in the bivalves are alarming as to the severity of the issue and are evident of a constant nylon load, through several point and non-point sources to the marine environment. Polyester was only evident in the bivalves with a high proportion enumerated. Polyester being the most predominant type of plastic found in the environment it is evident that it exerts a direct effect on bioaccumulation in bivalves. The ocean are severely polluted with plastic commodities sourced from polyester such as plastic bottles.

4.5 Health risks and Toxicity to humans

Seafood is a popular primary source of protein with worldwide consumption reaching 20kg/year per capita and imports/exports contributing to $132.6 billion to the global economy (Karbalaei et al., 2018; Prata et al., 2020; Smith et al., 2018). Seafood harvesting is culturally important in New Zealand, with 450,000 tonnes of seafood harvested recreationally and commercially per year (*Seafood Industry | Seafood New Zealand*, n.d.). In 2020 exports

in seafood from New Zealand contributed $2.0 billion to the economy, therefore, seafood is considered a valuable commodity in New Zealand that could be at risk due to microplastic pollution (*Seafood Industry | Seafood New Zealand*, n.d.).

Microplastic contamination of seafood and human consumption, became an increasing concern regarding worldwide food availability and security (Sharma & Chatterjee, 2017; Smith et al., 2018; Van Cauwenberghe & Janssen, 2014). Furthermore, due to their small size, microplastics are consumed by an array of biota which then transfer up into the food chain (Dawson et al., 2021; Prinz & Korez, 2020). The effects of microplastic pollution on human health is a topic that is understudied, however, some emerging literature in the last decade started investigating this issue (Karbalaei et al., 2018; Prata et al., 2020; Sharma & Chatterjee, 2017; Smith et al., 2018). Seafood are potential vectors of microplastic contamination with implications to humans through unintentional ingestion of microplastic particles present in the seafood (Sharma & Chatterjee, 2017; Smith et al., 2018). Microplastic particles are hydrophobic with large surface areas which result in chemical toxins adhering to the plastic particles (Brennecke et al., 2016). Research by Cox et al (2019) found that consumers ingest 39,000 to 52,000 particles annually (Dawson et al., 2021). Shellfish species are eaten whole, without gut removal, which enables a direct transfer of microplastic particles to humans (Karbalaei et al., 2018; Prata et al., 2020). Research noted that microplastic particles lodge within the cells and tissues of biota, resulting in chronic biological defects and persistence of plastic particles in the animal (Bour et al., 2018; Halstead et al., 2018; Smith et al., 2018). Furthermore, consideration should be given to the handling and processing of seafood as another vector of microplastic contamination and transfer to human consumers (Kedzierski et al., 2020; Smith et al., 2018; Wakkaf et al., 2020).

Plastic toxicity cause human health effects through physical and chemical routes as illustrated in figure 15 (Prata et al., 2020).

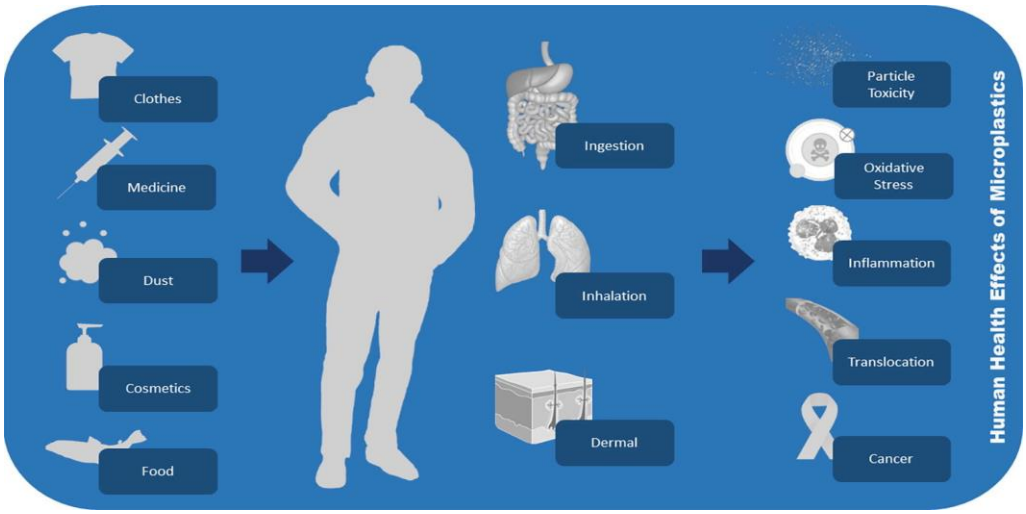

Figure 15. *Probable sources of plastic particles, routes of uptake, and health consequences of microplastic contamination in the human body (Prata et al., 2020).*

Several factors contribute to the severity of the physical toxicity experienced by humans, including characteristics of the chemical and individual sensitivity (Prata et al., 2020). Adverse effects of bioaccumulated microplastics in the human body is not well understood. However, baseline research confirmed effects such as an enhanced inflammatory response and disruption of the gastrointestinal environment, due to the ability of microplastic particles to translocate across cell walls and enter the lymphatic and circulatory system (Karbalaei et al., 2018; Prata et al., 2020). Furthermore, microplastic transfer to the human body initiate causal effects such as chromosomal modification which inadvertently promote cancer, obesity and infertility (Karbalaei et al., 2018; Prata et al., 2020).

Microplastics present several effects as chemistry disruptors in the human body resulting in adverse medical conditions (Karbalaei et al., 2018; Prata et al., 2020; Sharma & Chatterjee,

2017). Microplastic particles elicit inflammatory responses by releasing oxidizing compounds adhered to their surfaces which cause oxidative stress in humans (Prata et al., 2020; Valavanidis et al., 2013). Microplastic particles disrupt energy efficiency and uptake and cause an imbalance in energy homeostasis which affects the metabolism (Prata et al., 2020; Valavanidis et al., 2013). Microplastics cause an energy deficit due to inefficient feeding, a lack in digestive capabilities and reduce predatory performance (Prata et al., 2020; Valavanidis et al., 2013). Furthermore, exposure to microplastics may cause immune dysfunctions such as autoimmune diseases or immunosuppression, with immune compromised individuals being more susceptible to adverse effects (Prata et al., 2020; Valavanidis et al., 2013). Neurotoxicity initiates neurodegenerative diseases through oxidative stress, and the microglia is activated in the brain when in direct contact with microplastic particles (Prata et al., 2020; Valavanidis et al., 2013). These impacts on human health are of high concern and should be further evaluated through ongoing research.

4.6 Conclusion

The objectives of the thesis has been met and evidently demonstrates sediment accumulation at different tidal zones, and bivalve bioaccumulation throughout the study sites. Furthermore, this thesis highlights the increased numbers of microplastic particles found in *M. liliana* compared to *A. stutchburyii.*

Microplastic particles were found at all sites, with the recorded accumulation rates in sediments being of concern due to the pressure microplastics may cause the environment. Ongoing urbanization in The Bay of Plenty contributes to additional anthropogenic pressures with the potential for increasing pollution levels. Some properties of microplastic particles allow them to persist in the environment for extended times and with the probability of

extensive kinesis. Ocean currents, wave action and sediment sorting enable movement of microplastics towards and away from coastlines. They might originate from one location yet be deposited in another, presenting a new and emerging threat for New Zealand's shorelines.

The high numbers of microplastic particles found *in M. liliana*, *A. stutchburyi* and *P. subtriangulata* are indicative of the vulnerability of species exposed to microplastic pollution. Consistent pressure and exposure to microplastic particles could possibly have a negative effect on growth and reproduction of species. Limited research has been done to demonstrate the effects of microplastic pollution on marine biota and represents an area for future research.

Earlier studies in New Zealand and internationally confirmed the presence of microplastic particles in the marine environment and several other ecosystems. This research established that significant numbers of microplastics were present in the sediment of the intertidal and high–tide areas in Tauranga Harbour, Ohiwa Harbour, and the eastern coastline. Additionally, significant numbers of microplastic particles were present in *M. liliana*, *A. stutchburyi* and *P. subtriangulata*. Similar morphotypes were extracted from both the sediment and bivalves with the exclusion of polyester only extracted from the bivalves and rayon only from sediment. The impacts on human health represent an area for future research and concern. Microplastic pollution may have direct impacts on iwi and the general public through the inability to gather kaimoana in certain locations. The results from this study could be useful as baseline data and a useful tool when considering mitigation strategies.

4.7 Ongoing Research Recommendations

Further studies are recommended to provide a broader scope of the persistence of microplastic particles in both the environment and in biota. Constraints from this study

included (1) only three bivalve species were investigated, therefore, I suggest research being conducted on multiple filter and deposit feeders. This will lead to a greater understanding of the likelihood of feeding mode playing a part in increased levels of microplastic particles ingested, (2) the study was limited to Tauranga Harbour, Ohiwa Harbour, and locations on the eastern shoreline; therefore, I highly recommend an increase in spatial sampling along the Bay of Plenty coastline and the rest of New Zealand. Furthermore, laboratory feeding-studies should be conducted on different sized bivalves and a variety of species, to establish whether larger bivalves have higher microplastic ingestion rates compared to smaller ones.

Furthermore, specific research is needed to extrapolate the effects of chemical pollutants bioaccumulating in bivalves and their effects on human health upon ingestion. Microplastic fibres constitutes most of the plastic particles enumerated in this study as well as in earlier research, therefore, I recommend that a study investigating the effects microfibres exert on bivalves and other biota should be conducted. A deeper understanding is needed regarding different polymer types and their absorption rates in seafood and consequences for human health. Several medical issues are noted due to direct exposure to microplastic particles present in the human body, however dose response relationships could further be evaluated.

One's research is only as strong as the quality of one's data, and therefore to ensure greater comprehension of the problem the 'net needs to be cast' wider. In biological systems it is a fundamental requirement to know what is there, in order to assist with the proactive mitigation and minimisation of the problem over larger timescales.

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Appendices

***Appendix 1**. Abbreviations of polymer types that could be found in the sediment samples.*

Abbreviation	Polymer type
PE	polyethylene
PP	polypropylene
PET	Polyester (including PET)
PA	Polyamide/nylon
PMMA	polymethylmethacrylate
C&RC	cellulose and regenerated cellulose (e.g., cotton, rayon, or cellophane)
PU	polyurethane including spandex (polyether-polyurea copolymer)
PS	Polystyrene
PVC	polyvinylchloride
SY-ACN	styrene acrylonitrile copolymer
ACRY	Acrylic
RUB	rubber
Epoxy	Epoxy resin
PVA	polyvinyl acetate
Inorg	i.e., calcium carbonate, magnesium silicate and silica
Org	i.e., keratin, wood, paper
Incon	inconclusive - spectra was poor &/or HQI less than 60

Appendix 2. *List of definitions and calculations used in this research.*

Parameter	Description or calculation	Value	
Tare mass of collection jar and lid (g)	Average mass of 10 jars	464.87 g	
Gross mass of wet sediment collected (g)	Mass of wet sediment sample as collected including jar (without foil)	variable	
Net mass of wet sediment collected (g)	Gross mass of wet sediment - tare mass of jar and lid	variable	
Net mass of dry sediment collected (g)	Net mass of wet sediment - (net mass of dry sediment * moisture content)	variable	
Tare mass of beaker for analysis (g)	Tare mass of 800 mL beaker used for separation	variable	
Mass of wet sediment for analysis (g)	Mass of wet sediment transferred to 800 mL beaker for analysis	variable	
Gross mass of dry sediment for analysis (g)	Gross mass of sediment after drying including beaker	variable	
Net mass of dry sediment for analysis (g)	Gross mass of dry sediment for analysis - Tare mass of beaker for analysis	variable	
Moisture content (%)	(Mass of wet sediment - mass of dry sediment) / mass of wet sediment	variable	
Sieve size (um)	The mesh size sieves used for analysis	variable	
Tare mass of WPO beaker (g)	Tare mass of empty 600ml beaker/jar which particles collected on screen are transferred into for WPO treatment	variable	
Gross mass of 150 um fraction dried matter (70°C) (g)	Gross mass of 300um fraction beaker/jar + dried matter (70°C)	variable	
Net mass of microplastics & natural materials (g)	Gross mass of dried matter - Tare mass of WPO beaker	variable	
Number of H2O2 additions	Number of cycles of wet peroxide treatment (each 20mL aliquots of H2O2)	variable	
Total volume of sample (mL)	Volume of iron sulfate solution (20 mL) + (number of H2O2 additions x 20mL)	variable	
Mass of NaCl addition (g)	6 x (total volume of sample / 20)	variable	
Gross mass of 32µm fraction dried matter (70°C) (g)	Gross mass of 32um fraction beaker/jar + dried matter (70°C)	variable	
Count fragment	Tally of fragments observed under stereomicroscope, categories by size using EP50 camera	variable	
Count fibre	Tally of fibres observed under stereomicroscope, categories by size using EP50 camera	variable	
Count film	Tally of films observed under stereomicroscope, categories by size using EP50 camera	variable	
Summary	Summary of tally from above three categories		
Core dimensions	Dimensions of stainless-steel cores used for sampling	6cm diameter x 5cm depth	
Number of cores per sample	Number of cores collected within each quadrat pooled to form one sample	5	
Surface area sampled	(pi x r^2) x 5	141.35cm2	0.014135m2
Volume sampled	(pi x r2) x 5 x 5	706.86cm3	0.00070686m3
Number/m2	(Total microplastics counted / 0.014135) / (mass of sediment analysed / mass of sediment collected)		
Number/m3	(Total microplastics counted / 0.00070686) / (mass of sediment analysed / mass of sediment collected)		
Number/kg	(Total microplastics counted / (mass of sediment analysed (g) / 1000)		
Number mp/ species	Total number of microplastic particles counted in pooled homogenised sample per species per one location		
Number mp/g of tissue	Total number of microplastic particles counted in sample/ combined (pooled) weight of tissue (g).		

Appendix 3. *Sediment separation measurements and data.*

Location	HT#/IT#	Tare mass of collection jar and lid (g)	Gross mass of wet sediment collected (g)	Net mass of wet sediment collected (g)	Net mass of dry sediment collected (g)	Tare mass of beaker 800ml for analysis (g)	Mass of wet sediment for analysis (g)	Gross mass of dry sediment for analysis (g)	Net mass of dry sediment for analysis (g)	Moisture content (%)	Sieve size (um)	Tare mass of WPO beaker 600ml (g)	Gross mass of 150um fraction dried matter (70°C) (g)	Net mass of microplastics & natural materials (g)	Number of H2O2 additions	Total volume of sample (mL)	Mass of NaCl addition (g)
Mount Main Beach	HTA	464.87	1408.08	943.21	904.54	215.19	404.39	603.00	387.81	4%	150	173.25	177.73	4.48	2	50	12.5
	HTB	464.87	1426.87	962.00	921.97	210.66	403.24	597.12	386.46	4%	150	171.45	173.17	1.72	2	50	12.5
	HTC	464.87	1462.08	997.21	945.86	218.96	400.41	598.75	379.79	5%	150	173.65	174.73	1.08	2	50	12.5
	IT-1	464.87	1793.55	1328.68	1107.75	216.62	400.95	550.90	334.28	17%	150	173.35	173.96	0.61	2	50	12.5
	IT-2	464.87	1720.59	1255.72	1066.07	214.73	402.25	556.23	341.50	15%	150	173.03	174.07	1.04	2	50	12.5
	IT-3	464.87	1657.12	1192.25	1082.86	222.68	401.74	587.56	364.88	9%	150	176.01	176.75	0.74	2	50	12.5
Omanu Sewage outfall	HTA	464.87	1415.41	950.54	876.80	217.06	401.39	587.31	370.25	8%	150	172.64	173.09	0.45	2	50	12.5
	HTB	464.87	1398.54	933.67	869.43	211.11	400.58	584.13	373.02	7%	150	170.22	171.35	1.13	2	50	12.5
	HTC	464.87	1483.33	1018.46	920.38	215.14	400.40	576.98	361.84	10%	150	170.11	170.88	0.77	2	50	12.5
	IT-1	464.87	1432.44	967.57	745.27	215.54	401.39	524.71	309.17	23%	150	170.12	170.48	0.36	2	50	12.5
	IT-2	464.87	1772.79	1307.92	1011.90	216.10	400.43	525.90	309.80	23%	150	170.43	171.16	0.73	2	50	12.5
	IT-3	464.87	1745.44	1280.57	935.72	222.95	400.38	515.51	292.56	27%	150	171.23	172.11	0.88	2	50	12.5
Omokoroa	HTA	464.87	1418.22	953.35	910.54	219.47	401.10	602.56	383.09	4%	150	173.20	174.88	1.68	2	50	12.5
	HTB	464.87	1487.69	1022.82	983.17	217.12	402.20	603.73	386.61	4%	150	172.40	172.63	0.23	2	50	12.5
	HTC	464.87	1622.00	1157.13	1109.22	223.88	400.89	608.17	384.29	4%	150	175.32	175.62	0.30	2	50	12.5
	IT-1	464.87	1772.65	1307.78	1104.43	220.14	402.60	560.14	340.00	16%	150	172.65	173.37	0.72	2	50	12.5
	IT-2	464.87	1649.70	1184.83	937.53	222.28	401.02	539.60	317.32	21%	150	172.62	173.31	0.69	2	50	12.5
	IT-3	464.87	1692.46	1227.59	1014.80	224.57	402.80	557.55	332.98	17%	150	173.84	174.24	0.40	2	50	12.5
Ferguson Park/Matua	HTA	464.87	1625.97	1161.10	965.15	223.32	402.22	557.66	334.34	17%	150	172.64	174.26	1.62	4	90	22.5
	HTB	464.87	1563.20	1098.33	868.99	216.48	400.70	533.51	317.03	21%	150	172.91	174.3	1.39	4	90	22.5
	HTC	464.87	1178.50	713.63	608.50	215.75	401.60	558.19	342.44	15%	150	172.73	172.94	0.21	4	90	22.5
	IT-1	464.87	1608.48	1143.61	891.98	211.16	400.94	523.88	312.72	22%	150	169.01	169.68	0.67	4	90	22.5
	IT-2	464.87	1576.53	1111.66	804.18	215.38	401.31	505.69	290.31	28%	150	170.13	171.57	1.44	4	90	22.5
	IT-3	464.87	1578.22	1113.35	796.43	217.24	404.17	506.36	289.12	28%	150	169.71	170.36	0.65	4	90	22.5
Waikareao Estuary	HTA	464.87	1410.59	945.72	749.94	218.17	402.97	537.72	319.55	21%	150	171.29	171.96	0.67	2	50	12.5
	HTB	464.87	1417.62	952.75	910.81	219.86	402.79	604.92	385.06	4%	150	172.12	172.47	0.35	2	50	12.5
	HTC	464.87	1341.39	876.52	748.34	209.87	404.06	554.84	344.97	15%	150	170.06	171.26	1.20	2	50	12.5
	IT-1	464.87	1589.58	1124.71	889.80	217.51	402.51	535.95	318.44	21%	150	170.40	171.66	1.26	2	50	12.5
	IT-2	464.87	1558.72	1093.85	822.13	217.83	402.36	520.24	302.41	25%	150	175.66	176.67	1.01	2	50	12.5
	IT-3	464.87	1632.26	1167.39	907.85	209.83	401.26	521.88	312.05	22%	150	174.22	174.55	0.33	2	50	12.5
Tuapiro Point Beach	HTA	464.87	1513.52	1048.65	968.70	224.52	401.86	595.74	371.22	8%	150	174.09	174.80	0.71	2	50	12.5

	HTB	464.87	1487.05	1022.18	883.15	219.46	400.55	565.53	346.07	14%	150	173.47	174.42	0.95	2	50	12.5
	HTC	464.87	1410.58	945.71	882.50	220.12	400.19	593.56	373.44	7%	150	173.36	175.51	2.15	2	50	12.5
	IT-1	464.87	1550.87	1086.00	882.27	223.85	401.39	549.94	326.09	19%	150	173.21	173.82	0.61	2	50	12.5
	IT-2	464.87	1668.05	1203.18	931.77	217.11	403.89	529.89	312.78	23%	150	172.85	174.79	1.94	2	50	12.5
	IT-3	464.87	1252.42	787.55	673.12	222.28	400.13	564.27	341.99	15%	150	173.30	174.45	1.15	2	50	12.5
Tuapiro Point Estuary	HTA	464.87	1761.98	1297.11	988.63	216.57	401.22	522.37	305.80	24%	150	172.63	172.98	0.35	4	90	22.5
	HTB	464.87	1685.92	1221.05	879.32	215.92	404.26	507.04	291.12	28%	150	178.66	179.46	0.80	4	90	22.5
	HTC	464.87	1372.71	907.84	521.39	223.52	401.85	454.31	230.79	43%	150	169.86	172.00	2.14	4	90	22.5
	IT-1	464.87	1289.82	824.95	588.08	217.50	400.37	502.91	285.41	29%	150	174.93	179.46	4.53	4	90	22.5
	IT-2	464.87	1432.35	967.48	614.30	211.40	401.97	466.63	255.23	37%	150	171.56	175.13	3.57	4	90	22.5
	IT-3	464.87	1377.91	913.04	529.26	215.62	401.82	448.54	232.92	42%	150	171.21	174.66	3.45	4	90	22.5
Karewa Parade	HTA	464.87	1403.00	938.13	893.27	220.18	402.35	603.29	383.11	5%	150	171.41	172.93	1.52	1	40	10
	HTB	464.87	1335.31	870.44	853.94	209.04	400.95	602.39	393.35	2%	150	172.15	172.34	0.19	1	40	10
	HTC	464.87	1248.96	784.09	760.53	218.17	402.02	608.11	389.94	3%	150	171.59	171.72	0.13	1	40	10
	IT-1	464.87	1531.69	1066.82	999.19	217.14	402.71	594.32	377.18	6%	150	170.75	171.08	0.33	1	40	10
	IT-2	464.87	1537.71	1072.84	1030.20	216.79	400.32	601.20	384.41	4%	150	169.77	170.01	0.24	1	40	10
	IT-3	464.87	1449.46	984.59	945.85	215.39	402.55	602.10	386.71	4%	150	169.72	169.88	0.16	1	40	10
Papamoa Domain	HTA	464.87	1439.28	974.41	937.53	219.87	402.13	606.78	386.91	4%	150	170.18	170.32	0.14	1	40	10
	HTB	464.87	1434.06	969.19	933.85	217.51	401.55	604.42	386.91	4%	150	170.12	170.14	0.02	1	40	10
	HTC	464.87	1524.58	1059.71	998.17	224.53	401.58	602.79	378.26	6%	150	172.66	172.92	0.26	1	40	10
	IT-1	464.87	1595.08	1130.21	971.27	217.85	402.77	563.98	346.13	14%	150	169.04	169.05	0.01	1	40	10
	IT-2	464.87	1678.62	1213.75	1014.58	223.86	402.46	560.28	336.42	16%	150	171.33	171.37	0.04	1	40	10
	IT-3	464.87	1553.85	1088.98	945.95	210.81	401.46	559.54	348.73	13%	150	172.92	172.96	0.04	1	40	10
Maketu Coast	HTA	464.87	2048.29	1583.42	1416.51	209.84	401.96	569.43	359.59	11%	150	170.51	170.67	0.16	2	60	15
	HTB	464.87	1728.75	1263.88	1247.92	215.36	401.52	611.81	396.45	1%	150	170.81	171.34	0.53	2	60	15
	HTC	464.87	1575.08	1110.21	1093.34	222.31	402.78	618.97	396.66	2%	150	178.66	178.81	0.15	2	60	15
	IT-1	464.87	1922.72	1457.85	1287.07	222.78	401.39	577.15	354.37	12%	150	169.83	169.84	0.01	2	60	15
	IT-2	464.87	1848.16	1383.29	1225.43	219.49	402.22	575.81	356.32	11%	150	171.71	171.74	0.03	2	60	15
	IT-3	464.87	1673.34	1208.47	1190.50	216.11	402.12	612.25	396.14	1%	150	169.86	169.96	0.10	2	60	15
Maketu Estuary	HTA	464.87	1788.28	1323.41	1115.63	224.03	401.39	562.40	338.37	16%	150	172.65	172.93	0.28	1	40	10
	HTB	464.87	1905.41	1440.54	1285.73	219.61	401.99	578.40	358.79	11%	150	171.59	171.73	0.14	1	40	10
	HTC	464.87	1730.71	1265.84	1052.45	216.32	400.94	549.67	333.35	17%	150	174.15	174.32	0.17	1	40	10
	IT-1	464.87	1877.43	1412.56	1241.31	222.94	402.27	576.44	353.50	12%	150	173.03	173.18	0.15	1	40	10
	IT-2	464.87	1956.58	1491.71	1267.87	210.94	401.99	552.61	341.67	15%	150	172.14	172.22	0.08	1	40	10
	IT-3	464.87	1939.71	1474.84	1160.80	225.06	400.98	540.66	315.60	21%	150	174.26	175.09	0.83	1	40	10
Little Waihi Estuary 1 (Pukehina side)	HTA	464.87	1703.01	1238.14	1190.67	224.24	401.65	610.49	386.25	4%	150	174.41	174.42	0.01	2	60	15
	HTB	464.87	1694.76	1229.89	1174.09	211.63	401.12	594.55	382.92	5%	150	173.56	173.59	0.03	2	60	15
	HTC	464.87	1713.05	1248.18	1181.36	225.43	402.91	606.77	381.34	5%	150	174.52	174.54	0.02	2	60	15
	IT-1	464.87	1939.70	1474.83	1258.84	218.63	400.41	560.40	341.77	15%	150	173.64	173.88	0.24	2	60	15
	IT-2	464.87	1897.91	1433.04	1236.15	218.2	403.08	565.90	347.70	14%	150	173.62	173.71	0.09	2	60	15

	IT-3	464.87	1789.01	1324.14	1121.22	220.89	401.97	561.26	340.37	15%	150	181.22	181.32	0.10	2	60	15
Little Waihi Estuary 2	HTA	464.87	1939.38	1474.51	1187.42	223.13	403.29	547.90	324.77	19%	150	169.85	170.7	0.85	7	160	40
	HTB	464.87	1830.95	1366.08	1156.71	215.88	400.69	555.16	339.28	15%	150	169.21	169.49	0.28	7	160	40
	HTC	464.87	1964.15	1499.28	1309.29	220.30	404.75	573.76	353.46	13%	150	169.95	171.1	1.15	7	160	40
	IT-1	464.87	1971.01	1506.14	1211.44	217.42	402.37	541.06	323.64	20%	150	170.33	170.61	0.28	7	160	40
	IT-2	464.87	1828.47	1363.60	1180.31	218.31	400.47	564.95	346.64	13%	150	171.82	172.16	0.34	7	160	40
	IT-3	464.87	1849.48	1384.61	1136.20	218.78	401.87	548.55	329.77	18%	150	170.71	171.02	0.31	7	160	40
Ohope	HTA	464.87	1448.83	983.96	918.40	220.42	400.11	593.87	373.45	7%	150	175.28	175.36	0.08	1	40	10
	HTB	464.87	1581.97	1117.1	1032.67	215.49	400.36	585.59	370.10	8%	150	173.17	173.29	0.12	1	40	10
	HTC	464.87	1645.03	1180.16	1077.89	217.73	400.18	583.23	365.50	9%	150	173.32	173.36	0.04	1	40	10
	IT-1	464.87	1917.56	1452.69	1309.57	217.90	402.34	580.60	362.70	10%	150	171.21	171.29	0.08	1	40	10
	IT-2	464.87	1955.02	1490.15	1234.87	210.20	402.37	543.64	333.44	17%	150	173.22	173.53	0.31	1	40	10
	IT-3	464.87	1872.65	1407.78	1157.88	222.46	401.44	552.64	330.18	18%	150	176.95	177.03	0.08	1	40	10
Otumoetai	HTA	464.87	1738.61	1273.74	936.22	224.94	400.52	519.33	294.39	26%	150	169.78	170.28	0.50	6	140	35
	HTB	464.87	1737.30	1272.43	991.62	224.31	401.70	537.36	313.05	22%	150	170.77	171.23	0.46	6	140	35
	HTC	464.87	1767.34	1302.47	1044.21	220.47	401.09	542.03	321.56	20%	150	171.3	172.17	0.87	6	140	35
	IT-1	464.87	1770.36	1305.49	1039.35	223.15	402.23	543.38	320.23	20%	150	172.16	172.4	0.24	4	100	25
	IT-2	464.87	1688.18	1223.31	960.84	210.13	401.01	525.10	314.97	21%	150	169.73	170.66	0.93	4	100	25
	IT-3	464.87	1747.33	1282.46	1007.36	211.11	401.06	526.14	315.03	21%	150	170.21	170.49	0.28	4	100	25
Kauri Point	HTA	464.87	1536.41	1071.54	956.20	217.15	400.78	574.79	357.64	11%	150	170.49	170.56	0.07	2	60	15
	HTB	464.87	1575.90	1111.03	1016.85	214.88	400.74	581.65	366.77	8%	150	170.11	170.15	0.04	2	60	15
	HTC	464.87	1574.53	1109.66	1041.91	216.8	400.28	592.64	375.84	6%	150	172.94	173.06	0.12	2	60	15
	IT-1	464.87	1538.02	1073.15	652.36	219.92	402.13	464.37	244.45	39%	150	169.09	173.05	3.96	7	160	40
	IT-2	464.87	1666.10	1201.23	855.39	216.36	402.81	503.20	286.84	29%	150	171.61	172.34	0.73	7	160	40
	IT-3	464.87	1509.10	1044.23	870.20	222.51	401.12	556.78	334.27	17%	150	172.66	174.83	2.17	7	160	40
Katikati	HTA	464.87	1638.33	1173.46	1084.21	215.33	401.27	586.08	370.75	8%	150	178.87	178.88	0.01	1	40	10
	HTB	464.87	1496.09	1031.22	888.64	217.55	402.79	564.65	347.10	14%	150	169.96	170.17	0.21	1	40	10
	HTC	464.87	1527.63	1062.76	908.02	220.71	402.06	564.23	343.52	15%	150	170.6	170.76	0.16	1	40	10
	IT-1	464.87	1522.44	1057.57	964.66	217.29	402.95	584.84	367.55	9%	150	170.99	175.45	4.46	1	40	10
	IT-2	464.87	1483.66	1018.79	833.71	220.34	402.45	549.68	329.34	18%	150	174.37	174.62	0.25	1	40	10
	IT-3	464.87	1637.54	1172.67	944.89	224.41	402.23	548.51	324.10	19%	150	171.84	172.74	0.90	1	40	10
Opotiki	HTA	464.87	1430.66	965.79	926.34	210.29	402.50	596.35	386.06	4%	150	181.1	181.12	0.02	1	40	10
	HTB	464.87	1602.63	1137.76	1062.60	223.19	403.10	599.66	376.47	7%	150	174.54	174.59	0.05	1	40	10
	HTC	464.87	1511.60	1046.73	984.65	216.55	403.68	596.29	379.74	6%	150	173.58	173.6	0.02	1	40	10
	IT-1	464.87	1730.85	1265.98	1075.95	211.19	403.65	554.25	343.06	15%	150	170.07	170.08	0.01	1	40	10
	IT-2	464.87	1808.89	1344.02	1146.45	225.07	401.77	567.78	342.71	15%	150	173.56	173.75	0.19	1	40	10
	IT-3	464.87	1728.47	1263.6	996.23	222.77	402.33	539.97	317.20	21%	150	173.48	173.67	0.19	1	40	10
Waipapa	HTA	464.87	1529.11	1064.24	1049.25	215.35	401.03	610.73	395.38	1%	150	173.35	173.36	0.01	2	60	15
	HTB	464.87	1796.61	1331.74	1308.14	217.54	401.82	612.24	394.70	2%	150	171.68	171.69	0.01	2	60	15
	HTC	464.87	1811.40	1346.53	1334.82	209.85	400.26	606.63	396.78	1%	150	173.26	173.27	0.01	2	60	15
	IT-1	464.87	1776.89	1312.02	1279.17	218.17	400.59	608.73	390.56	3%	150	175.38	175.39	0.01	2	60	15
	IT-2	464.87	1775.96	1311.09	1291.90	217.95	402.43	614.49	396.54	1%	150	174.19	174.2	0.01	2	60	15
	IT-3	464.87	1805.35	1340.48	1323.50	219.51	400.32	614.76	395.25	1%	150	172.7	172.77	0.07	2	60	15
Pios Beach	HTA	464.87	1758.93	1294.06	1265.30	223.22	404.09	618.33	395.11	2%	150	172.2	172.27	0.07	1	40	10
	HTB	464.87	1758.04	1293.17	1267.15	222.6	400.51	615.05	392.45	2%	150	173.07	173.08	0.01	1	40	10

	HTC	464.87	1752.68	1287.81	1273.76	220.26	403.32	619.18	398.92	1%	150	173.25	173.26	0.01	1	40	10
	IT-1	464.87	1667.93	1203.06	1186.53	217.21	403.93	615.59	398.38	1%	150	177.03	177.23	0.20	1	40	10
	IT-2	464.87	1657.23	1192.36	1180.18	220.65	401.36	617.91	397.26	1%	150	171.28	171.29	0.01	1	40	10
	IT-3	464.87	1683.55	1218.68	1206.05	211.17	404.21	611.19	400.02	1%	150	174.32	174.33	0.01	1	40	10
Rangataua Bay	HTA	464.87	1798.44	1333.57	1092.04	211.37	403.77	542.01	330.64	18%	150	172.26	172.41	0.15	2	60	15
	HTB	464.87	1797.43	1332.56	1130.73	222.94	403.86	565.63	342.69	15%	150	173.1	173.6	0.50	2	60	15
	HTC	464.87	1608.68	1143.81	952.33	220.88	403.75	557.04	336.16	17%	150	170.2	170.25	0.05	2	60	15
	IT-1	464.87	1720.51	1255.64	1021.92	224.76	401.38	551.43	326.67	19%	150	170.4	171.28	0.88	2	60	15
	IT-2	464.87	1761.73	1296.86	1025.01	217.96	402.34	535.96	318.00	21%	150	171.43	171.63	0.20	2	60	15
	IT-3	464.87	1691.69	1226.82	987.50	210.36	404.88	536.26	325.90	20%	150	172.9	173.24	0.34	2	60	15
Ohiwa Harbour 1	HTA	464.87	1878.79	1413.92	1038.56	224.6	403.50	520.98	296.38	27%	150	170.16	171.85	1.69	2	60	15
	HTB	464.87	1690.50	1225.63	958.34	216.87	400.12	529.73	312.86	22%	150	170.78	173.32	2.54	2	60	15
	HTC	464.87	1894.82	1429.95	1084.46	219.53	404.25	526.11	306.58	24%	150	181.03	181.92	0.89	2	60	15
	IT-1	464.87	1758.20	1293.33	988.18	214.9	400.44	520.86	305.96	24%	150	171.61	172.19	0.58	2	60	15
	IT-2	464.87	1835.88	1371.01	1035.77	215.41	400.50	517.98	302.57	24%	150	172.15	172.89	0.74	2	60	15
	IT-3	464.87	1692.24	1227.37	953.73	216.18	401.62	528.26	312.08	22%	150	173.5	173.83	0.33	2	60	15
Ohiwa Harbour 2	HTA	464.87	1628.90	1164.03	1061.13	222.83	401.69	589.01	366.18	9%	150	176.97	177.07	0.10	1	40	10
	HTB	464.87	1822.32	1357.45	1231.04	222.37	401.41	586.40	364.03	9%	150	174.28	174.45	0.17	1	40	10
	HTC	464.87	1774.76	1309.89	1197.20	209.86	405.31	580.30	370.44	9%	150	170.51	170.87	0.36	1	40	10
	IT-1	464.87	1837.47	1372.6	1088.34	219.94	405.56	541.51	321.57	21%	150	173.5	173.9	0.40	2	60	15
	IT-2	464.87	1749.34	1284.47	973.49	210.85	403.95	517.00	306.15	24%	150	169.91	171.31	1.40	2	60	15
	IT-3	464.87	1491.50	1026.63	770.94	217.56	403.32	520.43	302.87	25%	150	169.76	170.61	0.85	2	60	15
Matakana Island 1	HTA	464.87	1478.49	1013.62	958.65	217.17	400.66	596.10	378.93	5%	150	171.6	172.02	0.42	1	40	10
	HTB	464.87	1435.92	971.05	922.27	223.93	401.16	604.94	381.01	5%	150	173.49	173.64	0.15	1	40	10
	HTC	464.87	1468.19	1003.32	944.84	209.9	400.93	587.46	377.56	6%	150	174.3	174.58	0.28	1	40	10
	IT-1	464.87	1853.18	1388.31	1184.27	224.59	402.80	568.19	343.60	15%	150	169.5	170.89	1.39	1	40	10
	IT-2	464.87	1565.70	1100.83	963.73	210.85	400.42	561.40	350.55	12%	150	169.05	169.13	0.08	1	40	10
	IT-3	464.87	1543.83	1078.96	926.04	214.92	400.34	558.52	343.60	14%	150	170.77	170.89	0.12	1	40	10
Matakana Island 2	HTA	464.87	1433.06	968.19	891.99	222.34	400.99	591.77	369.43	8%	150	172.15	173.23	1.08	1	40	10
	HTB	464.87	1459.66	994.79	907.60	222.81	400.72	588.41	365.60	9%	150	170.51	171.76	1.25	1	40	10
	HTC	464.87	1453.42	988.55	893.72	216.83	401.03	579.39	362.56	10%	150	176.96	177.6	0.64	1	40	10
	IT-1	464.87	1564.95	1100.08	881.81	217.55	401.43	539.33	321.78	20%	150	173.48	174.19	0.71	1	40	10
	IT-2	464.87	1691.25	1226.38	1045.86	219.52	403.68	563.78	344.26	15%	150	172.65	173.62	0.97	1	40	10
	IT-3	464.87	1565.50	1100.63	958.21	209.88	403.48	561.15	351.27	13%	150	169.76	170.51	0.75	1	40	10
Matakana Island 3	HTA	464.87	1497.66	1032.79	963.31	216.16	403.43	592.45	376.29	7%	150	181.01	181.04	0.03	1	40	10
	HTB	464.87	1484.51	1019.64	952.02	215.4	401.13	589.93	374.53	7%	150	174.28	174.57	0.29	1	40	10
	HTC	464.87	1440.79	975.92	879.39	219.91	406.34	586.06	366.15	10%	150	170.11	171.51	1.40	1	40	10
	IT-1	464.87	1568.14	1103.27	1010.51	217.88	401.42	585.55	367.67	8%	150	175.3	175.35	0.05	1	40	10
	IT-2	464.87	1654.93	1190.06	986.88	218.19	402.97	552.36	334.17	17%	150	174.16	174.29	0.13	1	40	10
	IT-3	464.87	1656.25	1191.38	890.85	220.19	402.97	521.51	301.32	25%	150	169.79	170.22	0.43	1	40	10

Matakana Island (inner harbour)	HTA	464.87	1560.57	1095.7	987.44	179.29	402.32	541.86	362.57	10%	150	170.83	170.87	0.04	1	40	10
	HTB	464.87	1606.24	1141.37	974.17	181.65	400.37	523.37	341.72	15%	150	178.69	178.98	0.29	1	40	10
	HTC	464.87	1562.68	1097.81	988.36	182.68	403.30	545.77	363.09	10%	150	173.41	174.12	0.71	1	40	10
	IT-1	464.87	1582.20	1117.33	960.93	181.33	400.20	525.51	344.18	14%	150	173.22	173.29	0.07	1	40	10
	IT-2	464.87	1754.80	1289.93	1114.54	183.49	402.30	531.09	347.60	14%	150	173.33	173.54	0.21	1	40	10
	IT-3	464.87	1607.58	1142.71	975.54	181.96	402.54	525.61	343.65	15%	150	171.59	171.64	0.05	1	40	10
Waihi Beach	HTA	464.87	1608.58	1143.71	997.50	181.2	401.30	531.20	350.00	13%	150	173.12	173.2	0.08	1	40	10
	HTB	464.87	1653.30	1188.43	1007.65	185.36	402.00	526.21	340.85	15%	150	173.45	173.9	0.45	1	40	10
	HTC	464.87	1743.20	1278.33	1159.65	182.54	401.98	547.20	364.66	9%	150	173.89	174.11	0.22	1	40	10
	IT-1	464.87	1690.30	1225.43	1034.75	181.33	401.22	520.12	338.79	16%	150	173.21	173.45	0.24	1	40	10
	IT-2	464.87	1478.20	1013.33	868.00	180.23	400.58	523.36	343.13	14%	150	173.56	174.31	0.75	1	40	10
	IT-3	464.87	1654.35	1189.48	1078.80	180.74	402.36	545.66	364.92	9%	150	173.54	173.89	0.35	1	40	10

Appendix 4. *Sediment microscopy and calculated results.*

Location	HT#/IT#	Net mass of dry sediment collected (g)	Net mass of dry sediment for analysis (g)	Total fragments (all sizes)	Total fibres (all sizes)	Total films (all sizes)	Total microplastics (all classes & sizes)	Number/m2	Mean number/m2	Number/m3	Mean number/m3	Number/kg (DW)	Mean number/kg (DW)
Mount Main Beach	HTA	904.54	387.81	0	8	0	8	1319.90		26397.61		20.63	
	HTB	921.97	386.46	0	9	0	9	1518.79		30375.30		23.29	
	HTC	945.86	379.79	0	6	0	6	1057.00	1298.56	21139.74	25970.88	15.80	19.91
	IT-1	1107.75	334.28	0	7	0	7	1640.86		32816.69		20.94	
	IT-2	1066.07	341.50	0	4	0	4	883.28		17665.39		11.71	
	IT-3	1082.86	364.88	0	5	0	5	1049.63	1191.26	20992.24	23824.78	13.70	15.45
Omanu Sewage outfall	HTA	876.80	370.25	2	12	0	14	2345.17		46902.77		37.81	
	HTB	869.43	373.02	2	7	0	9	1483.85		29676.54		24.13	
	HTC	920.38	361.84	3	11	0	14	2518.96	2115.99	50378.42	42319.24	38.69	33.54
	IT-1	745.27	309.17	2	15	0	17	2898.73		57973.75		54.99	
	IT-2	1011.90	309.80	3	12	0	15	3465.68		69312.64		48.42	
	IT-3	935.72	292.56	1	8	0	9	2036.18	2800.20	40723.03	56003.14	30.76	44.72
Omokoroa	HTA	910.54	383.09	1	3	0	4	672.52		13450.12		10.44	
	HTB	983.17	386.61	0	2	0	2	359.77		7195.38		5.17	
	HTC	1109.22	384.29	3	7	1	11	2245.91	1092.73	44917.57	21854.36	28.62	14.75
	IT-1	1104.43	340.00	1	3	0	4	919.10		18381.78		11.76	
	IT-2	937.53	317.32	0	7	0	7	1462.95		29258.67		22.06	
	IT-3	1014.80	332.98	0	4	1	5	1077.90	1153.32	21557.60	23066.02	15.02	16.28
Ferguson Park/Matua	HTA	965.15	334.34	4	2	0	6	1225.18		24503.26		17.95	
	HTB	868.99	317.03	2	3	1	6	1163.34		23266.52		18.93	
	HTC	608.50	342.44	1	2	0	3	377.09	921.87	7541.67	18437.15	8.76	15.21
	IT-1	891.98	312.72	0	2	0	2	403.53		8070.40		6.40	
	IT-2	804.18	290.31	0	3	1	4	783.78		15675.40		13.78	
	IT-3	796.43	289.12	0	2	2	4	779.42	655.57	15588.14	13111.31	13.84	11.34
Waikareao Estuary	HTA	749.94	319.55	2	3	0	5	830.05		16600.70		15.65	

	HTB	910.81	385.06	0	4	0	4	669.27		13385.26		10.39	
	HTC	748.34	344.97	0	5	0	5	767.24	755.52	15344.49	15110.15	14.49	13.51
	IT-1	889.80	318.44	0	1	3	4	790.62		15812.13		12.56	
	IT-2	822.13	302.41	0	3	0	3	576.91		11538.01		9.92	
	IT-3	907.85	312.05	0	2	0	2	411.59	593.04	8231.65	11860.60	6.41	9.63
Tuapiro Point Beach	HTA	968.70	371.22	2	5	0	7	1292.10		25841.66		18.86	
	HTB	883.15	346.07	0	6	0	6	1083.09		21661.50		17.34	
	HTC	882.50	373.44	1	10	0	11	1838.77	1404.65	36774.86	28092.67	29.46	21.88
	IT-1	882.27	326.09	0	3	0	3	574.15		11482.89		9.20	
	IT-2	931.77	312.78	0	1	0	1	210.72		4214.38		3.20	
	IT-3	673.12	341.99	0	2	0	2	278.45	354.44	5568.95	7088.74	5.85	6.08
Tuapiro Point Estuary	HTA	988.63	305.80	0	7	0	7	1600.79		32015.40		22.89	
	HTB	879.32	291.12	0	4	0	4	854.62		17092.25		13.74	
	HTC	521.39	230.79	0	9	0	9	1438.24	1297.88	28764.34	25957.33	39.00	25.21
	IT-1	588.08	285.41	0	3	0	3	437.25		8744.88		10.51	
	IT-2	614.30	255.23	0	2	0	2	340.50		6809.97		7.84	
	IT-3	529.26	232.92	0	3	0	3	482.19	419.98	9643.75	8399.53	12.88	10.41
Karewa Parade	HTA	893.27	383.11	0	6	0	6	989.58		19791.42		15.66	
	HTB	853.94	393.35	0	14	0	14	2149.91		42997.50		35.59	
	HTC	760.53	389.94	5	13	0	18	2483.32	1874.27	49665.79	37484.90	46.16	32.47
	IT-1	999.19	377.18	60	15	0	75	14054.09		281077.83		198.84	
	IT-2	1030.20	384.41	50	13	0	63	11942.93		238855.26		163.89	
	IT-3	945.85	386.71	35	7	0	42	7266.54	11087.85	145328.73	221753.94	108.61	157.11
Papamoa Domain	HTA	937.53	386.91	4	23	0	27	4627.88		92556.22		69.78	
	HTB	933.85	386.91	0	8	0	8	1365.85		27316.55		20.68	
	HTC	998.17	378.26	0	13	0	13	2426.62	2806.78	48531.63	56134.80	34.37	41.61
	IT-1	971.27	346.13	0	8	0	8	1587.94		31758.40		23.11	
	IT-2	1014.58	336.42	2	7	0	9	1919.96		38398.62		26.75	
	IT-3	945.95	348.73	20	14	0	34	6523.78	3343.89	130473.75	66876.92	97.50	49.12

Maketu Coast	HTA	1416.51	359.59	0	2	0	2	557.30		11145.76		5.56	
	HTB	1247.92	396.45	0	3	0	3	667.98		13359.39		7.57	
	HTC	1093.34	396.66	0	2	0	2	389.95	538.41	7798.91	10768.02	5.04	6.06
	IT-1	1287.07	354.37	1	6	0	7	1798.40		35967.56		19.75	
	IT-2	1225.43	356.32	0	8	0	8	1946.18		38922.99		22.45	
	IT-3	1190.50	396.14	1	4	0	5	1062.90	1602.49	21257.73	32049.42	12.62	18.28
Maketu Estuary	HTA	1115.63	338.37	0	2	0	2	466.45		9328.77		5.91	
	HTB	1285.73	358.79	0	3	1	4	1013.94		20278.54		11.15	
	HTC	1052.45	333.35	0	5	0	5	1116.64	865.67	22332.43	17313.25	15.00	10.69
	IT-1	1241.31	353.5	0	1	0	1	248.39		4967.71		2.83	
	IT-2	1267.87	341.67	1	8	0	9	2362.41		47247.44		26.34	
	IT-3	1160.80	315.6	2	7	0	9	2341.57	1650.79	46830.77	33015.30	28.52	19.23
Little Waihi Estuary 1 (Pukehina side)	HTA	1190.67	386.25	1	5	0	6	1308.33		26166.15		15.53	
	HTB	1174.09	382.92	0	3	0	3	650.66		13013.07		7.83	
	HTC	1181.36	381.34	0	3	0	3	657.41	872.13	13147.92	17442.38	7.87	10.41
	IT-1	1258.84	341.77	0	2	0	2	521.09		10421.58		5.85	
	IT-2	1236.15	347.7	0	4	0	4	1005.93		20118.41		11.50	
	IT-3	1121.22	340.37	0	3	0	3	699.04	742.02	13980.67	14840.22	8.81	8.72
Little Waihi Estuary 2	HTA	1187.42	324.77	0	5	0	5	1293.13		25862.28		15.40	
	HTB	1156.71	339.28	0	4	1	5	1205.81		24115.94		14.74	
	HTC	1309.29	353.46	0	2	1	3	786.07	1095.00	15721.13	21899.78	8.49	12.87
	IT-1	1211.44	323.64	0	1	0	1	264.78		5295.49		3.09	
	IT-2	1180.31	346.64	0	3	1	4	963.43		19268.31		11.54	
	IT-3	1136.20	329.77	0	2	0	2	487.43	571.88	9748.52	11437.44	6.06	6.90
Ohope	HTA	918.40	373.45	0	10	0	10	1739.57		34790.82		26.78	
	HTB	1032.67	370.1	0	8	0	8	1578.97		31578.97		21.62	
	HTC	1077.89	365.5	0	8	0	8	1668.85	1662.46	33376.60	33248.80	21.89	23.43
	IT-1	1309.57	362.7	0	10	0	10	2554.01		51079.46		27.57	
	IT-2	1234.87	333.44	0	14	0	14	3667.54		73349.82		41.99	

	IT-3	1157.88	330.18	0	5	0	5	1240.30	2487.28	24805.66	49744.98	15.14	28.23
Otumoetai	HTA	936.22	294.39	0	1	0	1	224.96		4499.07		3.40	
	HTB	991.62	313.05	0	4	0	4	896.26		17924.98		12.78	
	HTC	1044.21	321.56	0	1	0	1	229.70	450.31	4594.02	9006.02	3.11	6.43
	IT-1	1039.35	320.23	1	0	0	1	229.58		4591.62		3.12	
	IT-2	960.84	314.97	0	2	0	2	431.57		8631.33		6.35	
	IT-3	1007.36	315.03	0	5	0	5	1130.96	597.37	22618.88	11947.28	15.87	8.45
Kauri Point	HTA	956.20	357.64	0	4	0	4	756.49		15129.65		11.18	
	HTB	1016.85	366.77	0	3	0	3	588.34		11766.60		8.18	
	HTC	1041.91	375.84	0	4	0	4	784.38	709.74	15687.46	14194.57	10.64	10.00
	IT-1	652.36	244.45	0	4	0	4	755.09		15101.52		16.36	
	IT-2	855.39	286.84	0	5	0	5	1054.72		21094.17		17.43	
	IT-3	870.20	334.27	0	3	0	3	552.44	787.42	11048.66	15748.12	8.97	14.26
Katikati	HTA	1084.21	370.75	0	2	0	2	413.72		8274.24		5.39	
	HTB	888.64	347.1	0	2	0	2	362.20		7243.85		5.76	
	HTC	908.02	343.52	0	3	0	3	560.93	445.615	11218.43	8912.17	8.73	6.63
	IT-1	964.66	367.55	0	2	0	2	371.30		7425.99		5.44	
	IT-2	833.71	329.34	0	1	0	1	179.07		3581.29		3.04	
	IT-3	944.89	324.1	0	1	0	1	206.23	252.20	4124.47	5043.92	3.09	3.85
Opotiki	HTA	926.34	386.06	0	3	0	3	509.19		10183.68		7.77	
	HTB	1062.60	376.47	0	1	0	1	199.66		3993.05		2.66	
	HTC	984.65	379.74	0	1	0	1	183.42	297.42	3668.29	5948.34	2.63	4.35
	IT-1	1075.95	343.06	0	3	0	3	665.56		13310.97		8.74	
	IT-2	1146.45	342.71	0	2	0	2	473.26		9465.09		5.84	
	IT-3	996.23	317.2	0	2	0	2	444.32	527.71	8886.36	10554.14	6.31	6.96
Waipapa	HTA	1049.25	395.38	0	1	0	1	187.72		3754.30		2.53	
	HTB	1308.14	394.7	0	2	0	2	468.88		9377.44		5.07	
	HTC	1334.82	396.78	0	1	0	1	237.97	298.19	4759.27	5963.67	2.52	3.37
	IT-1	1279.17	390.56	0	2	0	2	463.35		9266.95		5.12	

	IT-2	1291.90	396.54	0	1	0	1	230.45		4609.02		2.52	
	IT-3	1323.50	395.25	0	0	1	1	236.86	310.22	4737.18	6204.38	2.53	3.39
Pios Beach	HTA	1265.30	395.11	0	0	1	1	226.53		4530.47		2.53	
	HTB	1267.15	392.45	0	3	0	3	685.18		13703.46		7.64	
	HTC	1273.76	398.92	0	3	0	3	677.59	529.77	13551.58	10595.17	7.52	5.90
	IT-1	1186.53	398.38	0	2	0	2	421.36		8427.09		5.02	
	IT-2	1180.18	397.26	0	0	0	0	0.00		0.00		0.00	
	IT-3	1206.05	400.02	0	3	0	3	639.80	353.72	12795.89	7074.33	7.50	4.17
Rangataua Bay	HTA	1092.04	330.64	0	1	0	1	233.63		4672.49		3.02	
	HTB	1130.73	342.69	0	4	0	4	933.60		18671.64		11.67	
	HTC	952.33	336.16	0	1	0	1	200.39	455.87	4007.82	9117.32	2.97	5.89
	IT-1	1021.92	326.67	0	1	0	1	221.29		4425.64		3.06	
	IT-2	1025.01	318	0	5	0	5	1140.02		22800.09		15.72	
	IT-3	987.50	325.9	0	5	0	5	1071.69	811.00	21433.40	16219.71	15.34	11.38
Ohiwa Harbour 1 (Wainui)	HTA	1038.56	296.38	0	2	0	2	495.74		9914.66		6.75	
	HTB	958.34	312.86	0	2	0	2	433.35		8666.94		6.39	
	HTC	1084.46	306.58	0	2	0	2	500.43	476.51	10008.46	9530.02	6.52	6.55
	IT-1	988.18	305.96	0	3	0	3	685.39		13707.55		9.81	
	IT-2	1035.77	302.57	0	4	0	4	968.59		19371.56		13.22	
	IT-3	953.73	312.08	0	2	0	2	432.35	695.44	8646.83	13908.65	6.41	9.81
Ohiwa Harbour 2 (Kutarere)	HTA	1061.13	366.18	0	1	0	1	204.98		4099.58		2.73	
	HTB	1231.04	364.03	0	2	0	2	478.42		9568.24		5.49	
	HTC	1197.20	370.44	0	4	0	4	914.43	532.61	18288.33	10652.05	10.80	6.34
	IT-1	1088.34	321.57	0	1	0	1	239.40		4788.01		3.11	
	IT-2	973.49	306.15	0	0	0	0	0.00		0.00		0.00	
	IT-3	770.94	302.87	1	2	0	3	540.17	259.86	10803.19	5197.07	9.91	4.34
Matakana Island 1 (South end)	HTA	958.65	378.93	0	3	0	3	536.86		10737.10		7.92	
	HTB	922.27	381.01	0	1	0	1	171.22		3424.45		2.62	
	HTC	944.84	377.56	0	2	0	2	354.03	354.04	7080.56	7080.70	5.30	5.28

	IT-1	1184.27	343.6	0	0	0	0	0.00		0.00		0.00	
	IT-2	963.73	350.55	0	0	0	0	0.00		0.00		0.00	
	IT-3	926.04	343.6	0	1	0	1	190.64	63.55	3812.79	1270.93	2.91	0.97
Matakana Island 2 (sewage outfall)	HTA	891.99	369.43	0	4	0	4	683.17		13663.24		10.83	
	HTB	907.60	365.6	0	3	0	3	526.81		10536.06		8.21	
	HTC	893.72	362.56	0	1	0	1	174.37	461.45	3487.29	9228.86	2.76	7.26
	IT-1	881.81	321.78	0	2	0	2	387.69		7753.74		6.22	
	IT-2	1045.86	344.26	0	1	0	1	214.90		4297.88		2.90	
	IT-3	958.21	351.27	0	1	0	1	192.96	265.18	3859.10	5303.57	2.85	3.99
Matakana Island 3 (North end)	HTA	963.31	376.29	0	1	0	1	181.09		3621.68		2.66	
	HTB	952.02	374.53	0	2	0	2	359.61		7192.14		5.34	
	HTC	879.39	366.15	0	2	0	2	339.78	293.49	6795.50	5869.77	5.46	4.49
	IT-1	1010.51	367.67	0	2	0	2	388.83		7776.41		5.44	
	IT-2	986.88	334.17	0	3	0	3	626.70		12533.84		8.98	
	IT-3	890.85	301.32	0	3	0	3	627.40	547.64	12547.74	10952.66	9.96	8.12
Matakana Island (inner harbour)	HTA	987.44	362.57	0	4	0	4	770.59		15411.56		11.03	
	HTB	974.17	341.72	0	2	0	2	403.31		8066.06		5.85	
	HTC	988.36	363.09	0	1	0	1	192.55	455.48	3850.93	9109.52	2.75	6.55
	IT-1	960.93	344.18	0	2	0	2	394.98		7899.52		5.81	
	IT-2	1114.54	347.6	0	2	0	2	453.62		9072.20		5.75	
	IT-3	975.54	343.65	0	1	0	1	200.80	349.80	4016.00	6995.91	2.91	4.82
Waihi Beach	HTA	997.50	350.00	0	2	0	2	403.20		8063.87		5.71	
	HTB	1007.65	340.85	0	3	0	3	627.35		12546.87		8.80	
	HTC	1159.65	364.66	1	1	0	2	449.90	493.48	8997.77	9869.50	5.48	6.67
	IT-1	1034.75	338.79	0	2	0	2	432.09		8641.77		5.90	
	IT-2	868.00	343.13	1	2	0	3	536.82		10736.17		8.74	
	IT-3	1078.80	364.92	0	3	0	3	627.34	532.09	12546.72	10641.55	8.22	7.62

Appendix 5. *Bivalve measurements and calculated results.*

Location	Species	Weight with shell (g)	Size (mm)	Weight of tissue per bivalve (g)	Tarred weight of empty 250ml conical flask (g)	Combined weight of wet tissue (g)	Fragments	Films	Fibres	Total # of MP	# Of MP per g of tissue
Waimapu/ Grace Road	*Macomona liliana*	2.32	20	0.66							
		2.89	23	1.13							
		2.52	27	1.23							
		3.48	23	0.94							
		1.41	27	1.12							
		2.25	30	1.42							
		1.88	18	0.86							
		3.91	32	1.57							
		2.79	26	1.29							
		1.94	21	0.78							
		2.53	30	1.21							
		2.19	21	0.85							
		1.85	20	0.71							
		1.16	19	0.51							
		1.29	18	0.50							
	mean	2.29	23.67	0.99	146.13	14.78	2	1	3	6	0.4
	SD	0.77	4.67	0.33							
Omokoroa	*Macomona liliana*	3.34	28	1.52							
		3.46	28	1.45							
		3.18	27	1.42							
		2.52	24	0.95							
		3.00	25	1.30							

		2.36	25	1.09							
		2.23	24	0.86							
		2.20	22	1.03							
		2.83	27	1.27							
		3.24	28	1.24							
		2.86	27	1.13							
		2.51	26	1.03							
		3.99	31	1.63							
	mean	2.90	26.31	1.22	148.72	15.92	0	0	0	0	0
	SD	0.53	2.32	0.23							
Otumoetai	*Macomona liliana*	6.30	37	2.62							
		1.38	23	0.62							
		7.14	38	3.57							
		3.37	29	1.52							
		7.46	36	3.84							
		6.08	34	3.18							
		6.50	35	2.66							
		2.23	26	0.99							
		3.43	28	1.52							
		2.41	27	1.00							
	mean	4.63	31.30	2.15	139.70	21.52	0	0	3	3	0.1
	SD	2.17	5.02	1.11							
Tuapiro Estuary	*Macomona liliana*	7.06	35	2.74							
		3.6	30	1.83							
		8.91	35	3.60							
		2.66	27	0.96							

		2.39	29	1.11							
		3.23	29	1.22							
		7.60	36	3.32							
		7.54	37	3.42							
		1.40	22	0.61							
		1.95	23	0.75							
		0.68	18	0.23							
	mean	4.27	29.18	1.80	164.83	19.79	10	0	1	11	0.6
	SD	2.92	6.29	1.25							
Tuapiro Ocean	*Macomona liliana*	3.72	29	1.56							
		3.23	28	1.56							
		2.50	26	1.08							
		2.22	26	1.08							
		4.19	30	1.75							
		2.55	25	1.01							
		3.09	29	1.39							
		3.49	28	1.71							
	mean	3.12	27.63	1.39	144.41	11.14	7	0	2	9	0.8
	SD	0.67	1.77	0.30							
Welcome Bay/ Rotary Park	*Macomona liliana*	3.20	28	1.49							
		2.98	28	1.30							
		2.81	28	1.07							
		1.35	22	0.51							
		1.80	24	0.95							

		1.63	24	0.69							
		3.80	33	1.49							
		2.23	27	1.01							
		1.37	22	0.56							
		4.22	36	1.52							
		5.51	35	2.30							
		2.74	29	0.88							
		2.30	26	1.08							
		1.72	22	0.77							
	mean	2.69	27.43	1.12	142.16	17.21	0	0	3	3	0.2
	SD	1.20	4.64	0.48							
Pahoia 1	*Macomona liliana*	5.29	34	2.10							
		6.36	38	1.79							
		5.02	32	2.33							
		5.83	39	1.97							
		4.64	34	1.95							
		4.78	33	2.11							
		3.77	34	1.50							
		4.16	35	1.64							
		4.05	36	1.69							
		4.87	33	2.40							
		7.39	38	3.10							
		3.33	36	1.59							
	mean	4.96	35.17	2.01	151.44	24.17	8	0	0	8	0.3
	SD	1.14	2.25	0.45							
Pahoia 2	*Macomona liliana*	3.29	27	1.34							

		2.40	26	1.16							
		3.15	22	1.47							
		3.38	28	1.52							
		3.85	28	1.15							
		5.38	36	2.03							
		3.29	29	1.41							
		3.11	27	1.44							
		3.05	28	1.05							
		4.08	32	1.61	146.49	15.82	7	0	1	8	0.5
		3.76	27	1.64							
	mean	3.52	28.18	1.44							
	SD	0.76	3.52	0.27							
Ongare Point	*Macomona liliana*	4.96	34	2.09							
		3.16	29	1.13							
		3.69	29	1.56							
		2.73	28	1.15							
		3.45	29	1.5							
		2.76	28	1.15							
		3.08	29	1.16							
		2.63	25	1.08							
		3.27	26	1.40							
		2.69	25	1.16							
		3.60	29	1.80							
	mean	3.27	28.27	1.38	148.83	15.18	9	0	2	11	0.7
	SD	0.67	2.49	0.33							
Waikareao Estuary	*Macomona liliana*	5.46	39	2.16							

		3.78	31	1.37							
		6.62	41	3.30							
		0.83	20	0.32							
		2.06	22	0.81							
		5.38	38	1.80							
		4.56	39	1.54							
		0.86	19	0.36							
		2.23	21	0.85							
		6.31	40	2.62							
	mean	3.81	31.00	1.51	151.62	15.13	0	0	2	2	0.1
	SD	2.19	9.45	0.98							
Otumoetai	*Austrovenus stutchburyi*	9.59	27	2.40							
		7.17	26	1.96							
		10.01	24	2.23							
		6.94	24	1.82							
		14.14	31	4.43							
		6.83	25	1.53							
		8.98	27	2.11							
		8.45	24	2.16							
		7.99	25	2.19							
		7.50	26	2.27							
		8.21	25	1.62							
		12.29	29	3.03							
		9.36	26	2.99							
	mean	9.04	26.08	2.36	149.95	30.74	0	0	0	0	0
	SD	2.15	2.06	0.76							

Tuapiro Estuary	*Austrovenus stutchburyi*	1.53	15	0.40							
		2.49	17	0.50							
		1.36	16	0.42							
		1.88	17	0.34							
		1.37	16	0.37							
		2.12	17	0.51							
		2.16	17	0.49							
		1.46	15	0.45							
		1.78	17	0.39							
		1.60	16	0.42							
		1.45	17	0.31							
		2.96	19	0.37							
		1.90	16	0.32							
		2.14	17	0.54							
	mean	1.87	16.57	0.42	162.78	5.83	2	0	0	2	0.3
	SD	0.47	1.02	0.07							
Tuapiro Ocean	*Austrovenus stutchburyi*	3.59	20	0.90							
		2.91	19	0.67							
		3.39	19	0.98							
		4.04	20	1.38							
		4.67	22	1.02							
		3.42	20	0.88							
		3.00	21	0.76							
		4.92	22	1.54							
		3.33	18	1.00							
		2.69	17	0.69							
		5.38	23	1.41							

		3.84	22	1.03	148.89	12.26	1	0	0	1	0.1
	mean	3.77	20.25	1.02							
	SD	0.84	1.82	0.28							
Wairoa	*Austrovenus stutchburyi*	3.57	22	1.20							
		2.95	19	0.59							
		3.34	20	0.89							
		3.54	21	1.23							
		1.17	14	0.27							
		2.01	16	0.54							
		5.75	26	2.05							
		3.75	21	1.24							
		3.34	21	1.16							
		3.43	20	0.90							
		1.31	15	0.36							
		2.64	20	0.69							
		2.14	19	0.47							
		3.37	20	1.05	144.74	12.64				0	0
	mean	3.02	19.57	0.90							
	SD	1.16	3.03	0.47							
Welcome Bay/ Rotary Park	*Austrovenus stutchburyi*	2.39	17	0.46							
		1.16	12	0.25							
		1.99	17	0.34							
		1.60	14	0.36							
		2.23	17	0.53							
		1.85	14	0.61							
		1.61	17	0.38							

		1.76	13	0.35							
		2.61	18	0.74							
		1.28	12	0.29							
	mean	1.85	15.10	0.43	145.76	4.31	0	0	1	1	0.2
	SD	0.47	2.33	0.15							
Ongare Point	*Austrovenus stutchburyi*	5.44	24	1.53							
		3.35	23	0.98							
		2.80	21	0.64							
		4.86	24	1.22							
		4.77	24	0.96							
		4.22	23	1.2							
		3.01	22	0.77							
		3.37	22	0.91							
		4.26	24	1.30							
	mean	4.01	23.00	1.06	147.22	9.51	5	0	0	5	0.5
	SD	0.92	1.12	0.28							
Te Puna	*Austrovenus stutchburyi*	2.66	22	0.76							
		3.14	23	0.63							
		2.54	21	0.73							
		1.26	14	0.32							
		3.01	21	1.4							
		3.01	23	0.61							
		3.04	24	0.80							
		2.03	19	0.58							
		1.68	13	0.42							
		1.75	15	0.50							

		2.22	21	0.74	143.75	7.49	3	0	0	3	0.4
	mean	2.39	19.64	0.68							
	SD	0.65	3.88	0.28							
Waikareao Estuary	*Austrovenus stutchburyi*	1.66	18	0.41							
		2.43	21	0.51							
		1.57	17	0.39							
		1.62	18	0.38							
		1.52	17	0.32							
		2.09	22	0.53							
		3.02	23	0.71							
		1.38	17	0.37							
		2.36	21	0.68							
		1.74	20	0.35							
		1.54	19	0.45							
		2.18	21	0.43							
		1.17	14	0.32							
		3.24	24	0.71							
		2.27	21	0.56	142.75	7.12	0	0	0	0	0
	mean	1.99	19.53	0.47							
	SD	0.60	2.70	0.14							
Otumoetai	*Macomona liliana*	5.2	31	1.73		6.04	2	1	1	4	0.66
		2.24	25	1.6							
		4.39	31	0.75							
		2.95	26	1.06							
		1.83	22	0.9							
		3.87	28	1.47		5.2	1	0	0	1	0.19

		3.94	31	1.66							
		1.5	22	0.65							
		1.81	24	0.79							
		1.41	21	0.63							
		2.18	25	0.96		5.04	1	0	0	1	0.20
		2.06	25	0.76							
		5.33	32	2.41							
		1.71	23	0.91							
	Mean	2.89	26	1.16							
	SD	1.39	3.80	0.53	145.25	**16.28**	**4**	**1**	**1**	**6**	**0.37**
Otumoetai	*Austrovenus stutchburyi*	5.7	23	1.55		9.91	0	0	0	0	
		7.84	24	2.32							
		8.71	24	2.7							
		6.82	23	1.6							
		9.18	25	2.37							
		8.57	24	2.24		11.69	0	0	0	0	0
		6.84	22	2.02							
		6	21	1.92							
		9.77	22	2.53							
		10.63	26	3.5							
		9.84	26	3.11		10.33	0	0	1	1	0.10
		6.15	23	1.62							
		8.03	26	2.44							
		5.92	24	1.67							
		5.22	22	1.86							
	Mean	7.68	24	2.23							
	SD	1.73	1.59	0.57	142.8	**31.93**	**0**	**0**	**1**	**1**	**0.03**

Omokoroa	*Macomona liliana*	2.18	27	0.93		7.84	5	0	1	6	0.77
		4.24	28	1.93							
		4.17	32	1.65							
		3.28	28	1.55							
		4.16	31	2.22							
		5.76	35	2.71		9	2	1	0	3	0.33
		3.44	32	1.44							
		4.38	31	2.19							
		3.31	29	1.76							
		2.62	27	1.23							
		3.46	32	1.5		6.12	4	0	0	4	0.65
		2.98	29	1.28							
		2.61	28	1.02							
		3.4	29	1.26							
		2.95	29	1.16							
	Mean	3.53	30	1.59							
	SD	0.90	2.27	0.50	143.9	**22.96**	**11**	**1**	**1**	**13**	**0.57**
Omokoroa	*Austrovenus stutchburyi*	7.85	29	2.43		8.35	5	0	1	6	0.72
		6.27	22	1.59							
		5.44	21	1.35							
		4.5	20	1.35							
		4.87	22	1.63							
		6.2	22	2.02		7.98	2	0	0	2	0.25
		5.06	22	1.98							
		4.97	23	1.36							

		5.34	23	1.6							
		3.79	29	1.02							
		4.29	20	1.01		6.25	0	0	0	0	0.00
		5.43	22	1.54							
		4.93	22	1.23							
		4.81	21	1.19							
		5.25	22	1.28							
	Mean	5.27	23	1.51							
	SD	0.96	2.72	0.39	145.9	**22.58**	**7**	**0**	**1**	**8**	**0.35**
Waipapa	*Macomona liliana*	2.21	26	0.98		3.23	3	0	2	5	1.55
		2.75	27	1.13							
		2.24	25	1.12							
		4.2	31	1.8		3.99	2	0	0	2	0.50
		3.36	29	1.33							
		1.6	24	0.86							
		2.88	29	1.19		3.33	1	0	1	2	0.60
		2.68	27	1.06							
		2.35	25	1.08							
	Mean	2.70	27	1.17							
	SD	0.75	2.29	0.27	142.6	**10.55**	**6**	**0**	**3**	**9**	**0.85**
Waipapa	*Austrovenus stuchburyi*	1.05	14	0.34		0.73	0	2	0	2	2.74
		1.61	16	0.39							
		1.18	14	0.37		1.09	0	1	0	1	0.92
		2.79	19	0.72							
		1.55	15	0.42		0.79	0	0	0	0	0.00
		1.55	15	0.37							

	Mean	1.62	16	0.44							
	SD	0.62	1.87	0.14	141.3	**2.61**	**0**	**3**	**0**	**3**	**1.15**
Katikati	*Macomona liliana*	3.88	30	1.4		4.92	1	0	0	1	0.20
		3.51	30	1.42							
		2.66	27	1.01							
		2.58	27	1.09							
		7.02	37	2.71		5.58	1	0	0	1	0.18
		3.66	30	1.32							
		2.48	28	1.02							
		1.45	24	0.53							
		3.88	31	1.44		5.21	1	0	0	1	0.19
		3.36	31	1.44							
		3.77	31	1.53							
		1.81	24	0.8							
	Mean	3.34	29	1.31							
	SD	1.42	3.54	0.54	142.62	**15.71**	**3**	**0**	**0**	**3**	**0.19**
Ongare Point	*Macomona liliana*	5.96	36	2.6		9.87	4	0	0	4	0.41
		4.46	34	2.01							
		4.6	34	2.2							
		4.82	35	2.5							
		1.15	23	0.56							
		3.95	33	1.67		6.64	1	0	2	3	0.45
		3.42	32	1.44							
		3.88	32	1.71							
		3.31	32	1.43							
		0.82	20	0.39							

		4.24	33	1.86		7.79	2	1	1	4	0.51
		3.92	31	1.78							
		6.06	36	3.04							
		1.15	21	0.5							
		1.24	23	0.61							
	Mean	3.53	30	1.62							
	SD	1.71	5.59	0.82	143.52	**24.3**	**7**	**1**	**3**	**11**	**0.45**
Ongare Point	*Austrovenus stutchburyi*	4	21	1.25		6.69	1	0	1	2	0.30
		4.43	22	1.35							
		4.56	21	1.2							
		3.96	21	1.43							
		5.03	21	1.46							
		5.08	23	1.41		7.88	1	0	0	1	0.13
		4.33	21	1.04							
		5.66	22	2							
		5.27	22	1.36							
		8.32	27	2.07							
		3.8	20	1.24		7.14	3	0	0	3	0.42
		4.65	21	1.21							
		5.46	22	1.57							
		6.29	24	2.15							
		3.69	21	0.97							
	Mean	4.97	22	1.45							
	SD	1.19	1.71	0.36	141.2	**21.71**	**5**	**0**	**1**	**6**	**0.28**
Pios Beach	*Macomona liliana*	2.86	28	1.3		4.46	4	0	0	4	0.90
		3.11	29	1.23							

		1.41	22	0.65							
		1.24	21	0.55							
		1.52	24	0.73							
		4.37	32	1.76		5.1	3	0	0	3	0.59
		2.44	27	1.13							
		1.71	22	0.86							
		1.69	24	0.77							
		1.28	23	0.58							
		3.98	32	1.44		4.82	2	0	0	2	0.41
		2.98	25	0.91							
		1.96	26	0.81							
		2.03	25	0.86							
		1.61	22	0.8							
	Mean	2.28	25	0.96							
	SD	0.98	3.52	0.34	143.26	**14.38**	**9**	**0**	**0**	**9**	**0.63**
Pios Beach	*Austrovenus stutchburyi*	1.72	16	0.48		2.72	0	0	3	3	1.10
		2.46	18	0.59							
		2.61	18	0.82							
		1.36	14	0.33							
		1.88	16	0.5							
		1.37	15	0.43		2.62	0	0	0	0	0.00
		2.11	17	0.61							
		1.21	13	0.44							
		1.47	15	0.33							
		2.5	18	0.81							
		1.7	16	0.46		2.13	1	0	0	1	0.47
		1.89	17	0.48							

		1.25	14	0.36							
		0.91	14	0.29							
		2.21	17	0.54							
	Mean	1.78	16	0.50							
	SD	0.52	1.64	0.16	144.32	**7.47**	**1**	**0**	**3**	**4**	**0.54**
Tuapiro Point	*Macomona liliana*	2.16	26	0.92		4.55	4	0	0	4	0.88
		2.65	27	1.33							
		1.85	25	0.79							
		2.31	26	1.15							
		0.74	19	0.36							
		3.45	31	1.25		4.04	4	0	0	4	0.99
		2.09	26	0.91							
		2.2	26	0.9							
		1.1	20	0.49							
		1.15	19	0.49							
		2.85	28	1.16		4.31	5	0	0	5	1.16
		3.58	30	1.54							
		0.86	21	0.42							
		0.9	21	0.46							
		1.48	21	0.73							
	Mean	1.96	24	0.86							
	SD	0.92	3.94	0.37	144.98	**12.9**	**13**	**0**	**0**	**13**	**1.01**
Tuapiro Point	*Austrovenus stutchburyi*	4.23	21	1.31		6.54	0	0	1	1	0.15
		4.51	23	1.15							
		4.67	22	1.64							
		5	23	1.42							

		3.28	20	1.02							
		4.87	22	1.44		5.96	0	0	1	1	0.17
		4.4	22	1.17							
		3.44	20	0.9							
		2.87	20	0.96							
		5.21	22	1.49							
		3.93	22	1.05		4.79	0	0	0	0	0.00
		3.12	20	0.9							
		3.96	22	1.04							
		4.39	23	1							
		2.97	20	0.8							
	Mean	4.06	21	1.15							
	SD	0.77	1.19	0.25	143.69	**17.29**	**0**	**0**	**2**	**2**	**0.12**
Matahui	*Macomona liliana*	9.12	41	3.22		13.6	1	0	0	1	0.07
		6.95	38	2.62							
		5.85	35	2.31							
		7.43	40	2.99							
		6.01	35	2.46							
		9.11	38	3.25		14.68	0	0	0	0	0.00
		7.05	35	2.32							
		8.17	38	3.35							
		7.81	38	3.09							
		6.72	35	2.67							
		6.24	36	2.54		13.76	1	0	0	1	0.07
		9.05	38	3							
		7.61	37	3.15							
		6.53	36	2.68							

		6.18	36	2.39							
	Mean	7.32	37	2.80							
	SD	1.13	1.87	0.36	143.66	**42.04**	**2**	**0**	**0**	**2**	**0.05**
Rangataua Bay	*Macomona liliana*	11.92	41	4.68		19.47	6	0	3	9	0.46
		9.27	38	3.96							
		8.01	37	3.47							
		8.66	38	3.86							
		7.92	36	3.5							
		10.94	40	4.45		19.19	5	0	3	8	0.42
		9.91	41	4.09							
		8.07	38	3.6							
		8.902	40	4.32							
		6.67	34	2.73							
		10.14	40	4.63		18.36	5	0	1	6	0.33
		8.31	38	4.09							
		8.68	39	3.94							
		5.97	32	2.67							
		6.87	35	3.03							
	Mean	8.68	38	3.80							
	SD	1.60	2.62	0.63	142.88	**57.02**	**16**	**0**	**7**	**23**	**0.40**
Rangataua Bay	*Austrovenus stutchburyi*	2.46	16	0.14		1.07	2	0	0	2	1.87
		1.71	15	0.24							
		2.07	15	0.18							
		2.38	17	0.31							
		2.39	15	0.2							
		2.5	15	0.26		1.18	2	0	1	3	2.54

		2.25	16	0.28							
		2.14	14	0.24							
		1.66	13	0.18							
		2.31	14	0.22							
		2.03	13	0.21		0.76	4	0	1	5	6.58
		1.76	15	0.11							
		1.91	16	0.19							
		1.9	16	0.13							
		2.35	16	0.12							
	Mean	2.12	15	0.20							
	SD	0.28	1.16	0.06	143.33	**3.01**	**8**	**0**	**2**	**10**	**3.32**
Maketu Estuary	*Macomona liliana*	11.45	48	2.31		4.55	4	0	0	4	0.88
		11.47	43	2.24							
		1.44	26	0.32		2.43	2	0	0	2	0.82
		8.66	40	2.11							
		7.25	39	2.06		2.92	3	0	1	4	1.37
		3.45	31	0.86							
	Mean	7.29	38	1.65							
	SD	4.14	8.04	0.84	144.31	**9.9**	**9**	**0**	**1**	**10**	**1.01**
Maketu Estuary	*Austrovenus stutchburyi*	2.41	17	0.28		3	1	0	2	3	1.00
		6.5	24	1.15							
		4.83	21	0.75							
		2.92	18	0.34							
		3.86	21	0.48							
		3.33	18	0.25		4.07	0	0	2	2	0.49
		7.06	25	1.53							

		5.3	21	1.3							
		3.39	19	0.49							
		2.4	19	0.5							
		3.1	19	0.52		3.02	2	0	2	4	1.32
		5.07	22	0.85							
		4.13	21	0.6							
		3.08	18	0.4							
		3.61	20	0.65							
	Mean	4.07	20	0.67							
	SD	1.41	2.27	0.38	144.21	**10.09**	**3**	**0**	**6**	**9**	**0.89**
Ohiwa Harbour 1 (Wainui)	*Macomona liliana*	5.76	63	2.05		6.21	4	0	0	4	0.64
		5.47	62	2.02							
		4.9	66	2.14							
		9.01	75	3.16		7.44	5	0	0	5	0.67
		4.3	68	2.2							
		3.93	56	2.08							
		6.89	63	2.1		6.39	2	0	0	2	0.31
		4.75	67	2.31							
		3.36	55	1.98							
	Mean	5.37	64	2.23							
	SD	1.72	6.13	0.36	144.28	**20.04**	**11**	**0**	**0**	**11**	**0.55**
Ohiwa Harbour 1 (Wainui)	*Austrovenus stutchbury*i	3.53	45	0.24		1.59	0	0	0	0	0.00
		3.22	45	0.53							
		2.1	42	0.25							
		3.65	44	0.57							
		2.27	43	0.45		2.48	0	0	0	0	0.00

		3.46	45	0.77							
		3.26	46	0.5							
		3.98	46	0.76							
		2.74	42	0.35		1.7	0	0	1	1	0.59
		3.48	45	0.4							
		1.97	42	0.3							
		3.58	45	0.65							
	Mean	3.10	44	0.48							
	SD	0.67	1.53	0.18	143.98	**5.77**	**0**	**0**	**1**	**1**	**0.17**
Ohiwa Harbour 2 (Kutarere)	*Macomona liliana*	14.83	71	2.75		13.2	2	0	0	2	0.15
		18.53	77	4.18							
		14.09	76	1.58							
		11.53	70	2.3							
		9.41	71	2.39							
		15.47	75	2.83		9.67	0	0	0	0	0.00
		9.48	69	1.8							
		16.43	71	0.83							
		10.57	75	2.2							
		10	69	2.01							
		12.92	75	2.41		11.66	1	0	0	1	0.09
		12.52	75	3.13							
		11.84	73	1.97							
		13.95	71	2.44							
		6.01	65	1.71							
	Mean	12.51	72	2.30							
	SD	3.20	3.30	0.77	144.21	**34.53**	**3**	**0**	**0**	**3**	**0.09**

Ohiwa Harbour 2 (Kutarere)	*Austrovenus stutchburyi*	14.97	52	1.72		8.57	0	0	2	2	0.23
		13.37	55	2.48							
		13.48	55	2.06							
		7.51	51	1.21							
		8.42	51	1.1							
		11.48	55	2.16		8.6	0	0	3	3	0.35
		10.66	53	1.6							
		8.98	53	1.49							
		12.95	55	1.95							
		7.52	49	1.4							
		12.57	54	2.3		9.17	1	0	2	3	0.33
		15.33	55	2.16							
		10.5	53	2.11							
		11.51	51	1.61							
		8	50	0.99							
	Mean	11.15	53	1.76							
	SD	2.63	2.04	0.46	143.63	**26.34**	**1**	**0**	**7**	**8**	**0.30**
Little Waihi Estuary	*Macomona liliana*	24.36	80	3.43		6.37	3	0	0	3	0.47
		18.03	87	2.22							
		6.88	62	0.72							
		22.86	88	3.09		7.56	5	0	0	5	0.66
		20.98	85	3.3							
		6.72	65	1.17							
		21.76	84	2.9		9.88	3	0	0	3	0.30
		20.6	86	3.41							
		19.22	84	3.57							
	Mean	17.93	80	2.65							

	SD	6.58	9.71	1.05	144.31	**23.81**	**11**	**0**	**0**	**11**	**0.46**
Little Waihi Estuary	*Austrovenus stutchburyi*	10.96	57	1.54		4.06	0	0	2	2	0.49
		7.53	54	0.99							
		5.1	51	0.67							
		3.06	49	0.4							
		3.63	49	0.46							
		5.93	54	0.8		3.45	1	0	1	2	0.58
		6.22	53	0.77							
		5.66	50	0.84							
		4.31	51	0.62							
		3.04	49	0.42							
		5.63	51	0.87		4.2	0	0	1	1	0.24
		10.79	57	1.46							
		6.02	53	0.62							
		4.53	51	0.86							
		3.76	49	0.39							
	Mean	5.74	52	0.78							
	SD	2.44	2.72	0.35	142.98	**11.71**	**1**	**0**	**4**	**5**	**0.43**
Matakana Island 3	*Macomona liliana*	21.76	60	4.92		10.11	0	0	0	0	0.00
(Nothern end)		23.89	58	5.19							
		27.2	60	5.79		9.61	0	0	0	0	0.00
		15.64	53	3.82							
		11.87	46	2.74		7.62	0	0	0	0	0.00
		17.27	54	4.88							
	Mean	19.61	55	4.56							
	SD	5.69	5.38	1.10	143.78	**27.34**	**0**	**0**	**0**	**0**	**0.00**

Matakana Island 3	*Austrovenus stutchburyi*	10.41	26	1.03		5.03	0	0	0	0	0.00
(Northern end)		7.62	24	1.38							
		8.64	23	1.01							
		7.46	23	0.66							
		6.3	23	0.95							
		8.5	25	1.11		4.13	0	0	1	1	0.24
		9.61	27	1.01							
		7.49	23	0.62							
		6.28	22	0.78							
		5.95	21	0.61							
		8.8	25	0.82		4.52	0	0	0	0	0.00
		6.83	24	1.11							
		8.84	23	1.04							
		7.39	22	1.01							
		4.95	22	0.54							
	Mean	7.67	24	0.91							
	SD	1.48	1.64	0.23	143.56	**13.68**	**0**	**0**	**1**	**1**	**0.07**
Matakana Island 4	*Macomona liliana*	4.83	30	1.94		10.24	3	0	0	3	0.29
		5.83	32	2.36							
		4.9	31	2							
		5.27	30	2.05							
		4.73	30	1.89							
		4.53	28	1.86		9.31	1	0	1	2	0.21
		4.56	29	1.72							
		6.08	32	2.16							
		3.93	29	1.73							

		4.05	29	1.84							
		4.22	27	1.76		9.5	1	0	1	2	0.21
		4.98	29	2.02							
		3.89	28	1.82							
		5.19	29	2.14							
		4.13	29	1.76							
	Mean	4.74	29	1.94							
	SD	0.66	1.41	0.18	173.69	**29.05**	**5**	**0**	**2**	**7**	**0.24**
Karewa Parade	*Paphies subtriangulata*	28.6	57	7.3		25	1	0	2	3	0.12
		24.48	50	6.42							
		18.28	48	5.3							
		11.73	42	3.61							
		8.83	37	2.37							
		25.83	55	7.13		24.38	1	0	0	1	0.04
		20.71	48	6.35							
		16.23	46	4.57							
		12.28	42	3.8							
		8.28	38	2.53							
		23.06	53	6.53		23.52	1	0	0	1	0.04
		24.47	52	6.76							
		13.42	44	4.11							
		10.4	40	3.46							
		8.27	36	2.66							
	Mean	16.99	46	4.86							
	SD	7.08	6.70	1.78	174.23	**72.9**	**3**	**0**	**2**	**5**	**0.07**

Waihi Beach 1	*Paphies subtriangulata*	14.93	45	3.06		8.4	0	0	1	1	0.12
		14.23	46	3.05							
		13.34	41	2.29							
		18.21	48	3.41		8.48	1	0	2	3	0.35
		13.22	45	2.74							
		13.72	44	2.33							
		16.03	47	3.02		7.74	1	0	0	1	0.13
		14.65	45	2.5							
		12.52	41	2.22							
	Mean	14.54	45	2.74							
	SD	1.73	2.40	0.42	174.56	**24.62**	**2**	**0**	**3**	**5**	**0.20**
Waihi Beach 2	*Paphies subtriangulata*	20.89	54	4.93		13.03	1	0	3	4	0.31
		14.91	47	3.62							
		11.86	42	2.51							
		11.31	40	1.97							
		20.52	53	4.64		14.17	1	0	2	3	0.21
		17.67	47	4.01							
		15	45	2.86							
		10.92	40	2.66							
		17.08	45	3.47		13.37	1	0	1	2	0.15
		19.62	45	3.38							
		16.71	46	3.55							
		12.48	41	2.97							
	Mean	15.75	45	3.38							
	SD	3.58	4.54	0.86	174.22	**40.57**	**3**	**0**	**6**	**9**	**0.22**
Papamoa Domain (Sunbrae Ave)	*Paphies subtriangulata*	20.6	51	5.64		22.52	0	0	0	0	0.00

		21.95	52	4.85							
		18.78	50	4.7							
		17.06	48	4.06							
		13.88	45	3.27							
		27.84	55	6.03		22.21	3	0	0	3	0.14
		17.9	49	4.83							
		15.27	49	4.48							
		13.68	45	3.7							
		13.63	46	3.17							
		16.23	47	4.41		23.21	2	0	0	2	0.09
		29.47	56	6.66							
		17.34	48	4.56							
		13.65	45	3.77							
		14.04	46	3.81							
	Mean	18.09	49	4.53							
	SD	5.02	3.49	0.99	173.54	**67.94**	**5**	**0**	**0**	**5**	**0.07**
Papamoa Domain (boat ramp)	*Paphies subtriangulata*	21.57	57	4.52		19.98	0	0	1	1	0.05
		20.36	45	4.23							
		15.78	49	3.83							
		15.06	46	4.16							
		16.25	45	3.24							
		31.43	53	6.94		21.28	1	0	1	2	0.09
		16.99	45	4.28							
		14.2	44	3.5							
		13.6	43	3.86							
		13.37	43	2.7							
		37.84	57	7.18		22.13	1	0	1	2	0.09

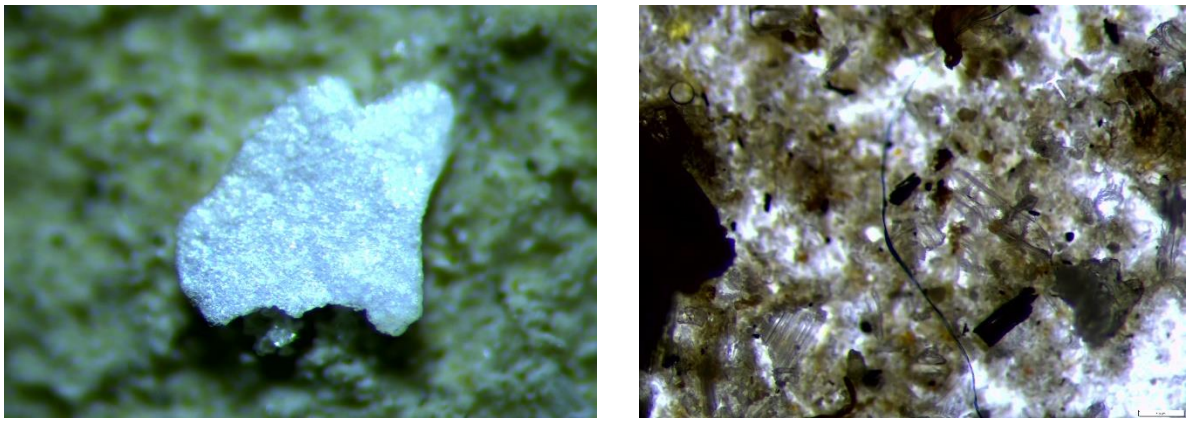
		18.13	48	4.52							
		15.76	45	4.23							
		12.49	42	3.24							
		12.69	42	2.96							
	Mean	18.37	47	4.23							
	SD	7.20	4.99	1.28	174.12	**63.39**	**2**	**0**	**3**	**5**	**0.08**
Matakana Island 1 (Southern end)	*Paphies subtriangulata*	17.41	45	4.32		12.67	0	0	0	0	0.00
		11.7	40	2.34							
		10.3	40	2.43							
		8.82	46	1.73							
		8.31	37	1.85							
		14.15	43	2.96		10.94	1	0	0	1	0.09
		10.32	37	2.53							
		8.37	36	1.97							
		8.55	36	1.88							
		6.72	32	1.6							
		8.66	37	2.23		10.02	0	0	0	0	0.00
		10.15	36	2.07							
		8.47	39	2.26							
		10.12	34	1.81							
		7.93	36	1.65							
	Mean	10.00	38	2.24							
	SD	2.72	3.94	0.68	173.65	**33.63**	**1**	**0**	**0**	**1**	**0.03**
Matakana Island 2 (Sewage outfall)	*Paphies subtriangulata*	18.33	45	2.53		15.61	2	0	1	3	0.19
		16.25	43	3.4							
		14.03	45	3.02							

		14.46	45	3.57							
		11.91	41	3.09							
		14.51	49	2.7		15.58	2	0	3	5	0.32
		13.37	49	3.37							
		15.97	53	3.66							
		11.12	47	3.42							
		11.64	48	2.43							
		16.57	54	3.74		17.51	1	0	2	3	0.17
		15.84	56	3.05							
		13.03	59	4.02							
		13.41	61	3.68							
		14.3	60	3.02							
	Mean	14.32	50	3.25							
	SD	2.01	6.44	0.46	174.36	**48.7**	**5**	**0**	**6**	**11**	**0.23**
Matakana Island 3 (North end)	*Paphies subtriangulata*	17.42	48	4.3		18.46	0	0	0	0	0.00
		16.25	46	3.98							
		14.6	44	3.62							
		14.78	47	3.38							
		12.41	42	3.18							
		16.52	47	4.51		17.71	0	0	2	2	0.11
		14.88	46	4.05							
		17.01	48	3.9							
		11.45	47	2.27							
		10.25	39	2.98							
		31.67	55	7.64		21.18	0	0	1	1	0.05
		16.63	47	4.43							
		13.14	42	3.42							

		11.34	43	2.77							
		13.07	43	2.92							
	Mean	15.43	46	3.82							
	SD	5.03	3.72	1.24	173.98	**57.35**	**0**	**0**	**3**	**3**	**0.05**
Matakana Island (inner harbour)	*Paphies subtriangulata*	19.96	50	4.69		21.52	1	0	2	3	0.14
		16.86	50	4.77							
		19.16	46	3.98							
		16.02	47	4.23							
		16.78	48	3.85							
		15.67	47	3.66		17.89	2	0	1	3	0.17
		15.21	45	3.56							
		12.43	45	3.51							
		14.49	45	3.83							
		14.6	46	3.33							
		21.68	48	5.58		18.67	2	0	2	4	0.21
		11.86	49	2.94							
		16.81	44	3.92							
		15.69	43	3.08							
		11.21	42	3.15							
	Mean	15.90	46	3.87							
	SD	2.90	2.41	0.71	174.12	**58.08**	**5**	**0**	**5**	**10**	**0.17**

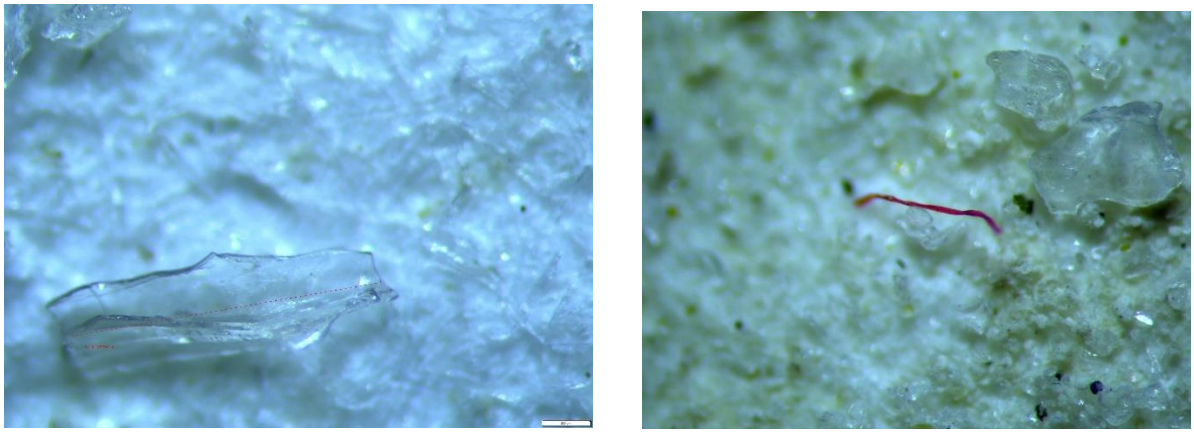
Appendix 6. *Images of some of the microplastic particles extracted from the sediment.*

A) **B)**



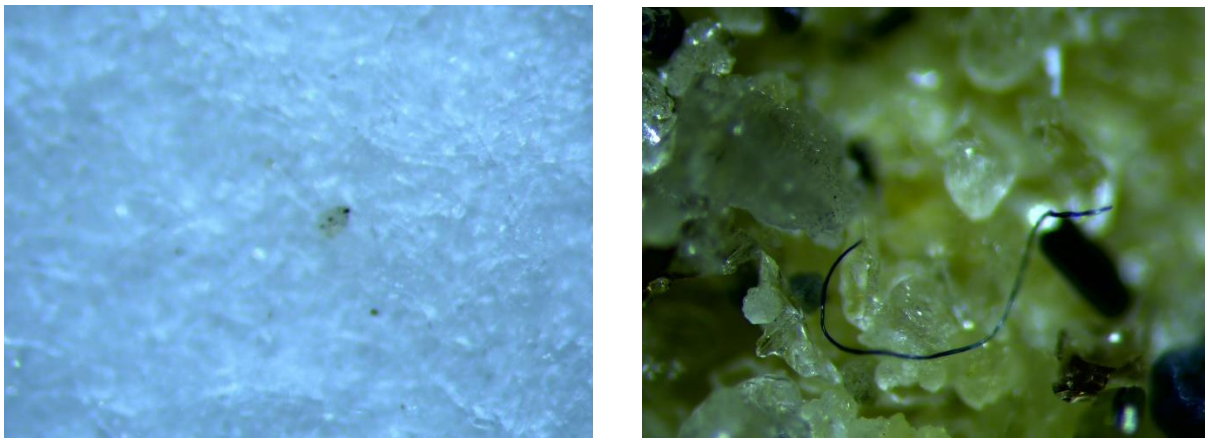
Microplastic A) fragment and B) fibre - HTC Omanu sewage outfall.

A) **B)**



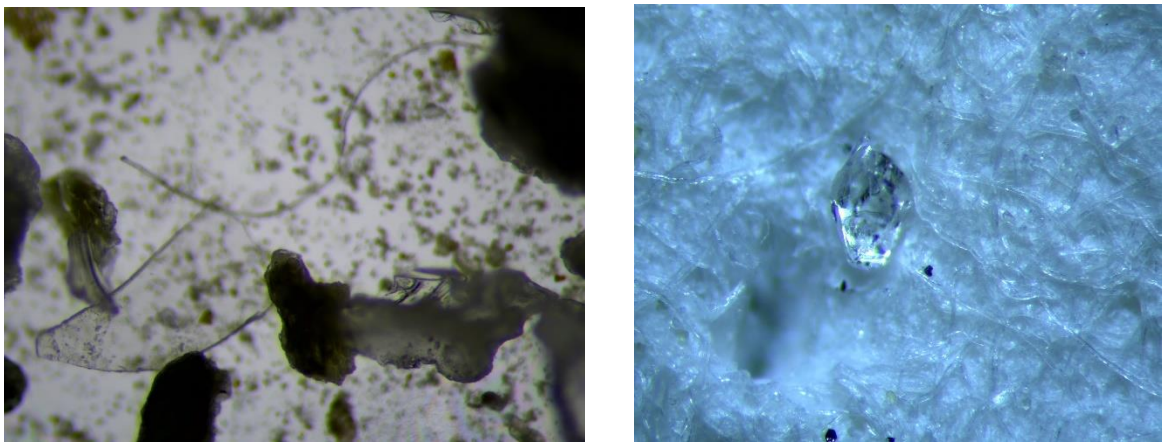
Microplastic A) fragment and B) fibre – IT-1 Omokoroa.

A) **B)**



Microplastic A) film and B) fibre – IT-2 Little Waihi Estuary

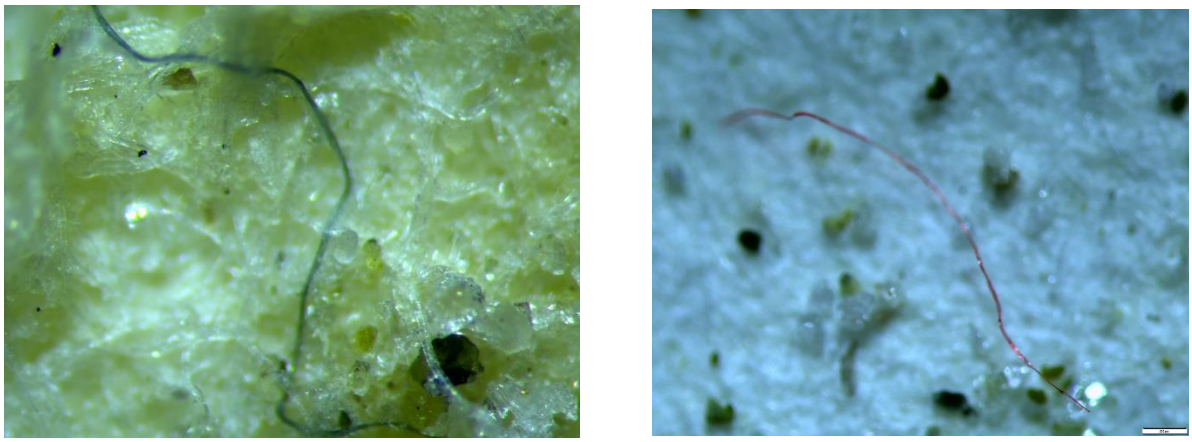
A) **B)**



Microplastic A) fibre & film and B) fragment – HTB Ferguson Park/ Matua.

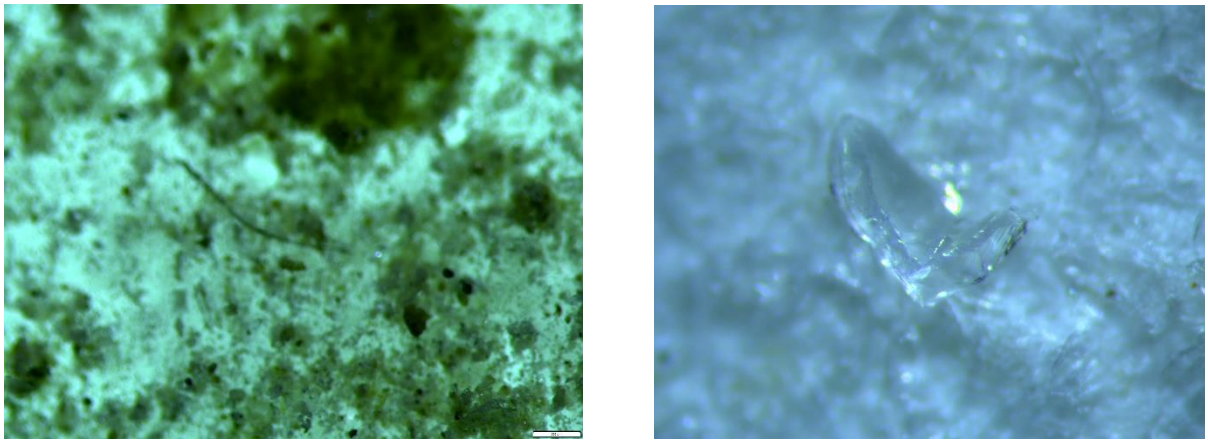
Appendix 7. *Images of some of the microplastic particles extracted from the bivalves.*

A) **B)**



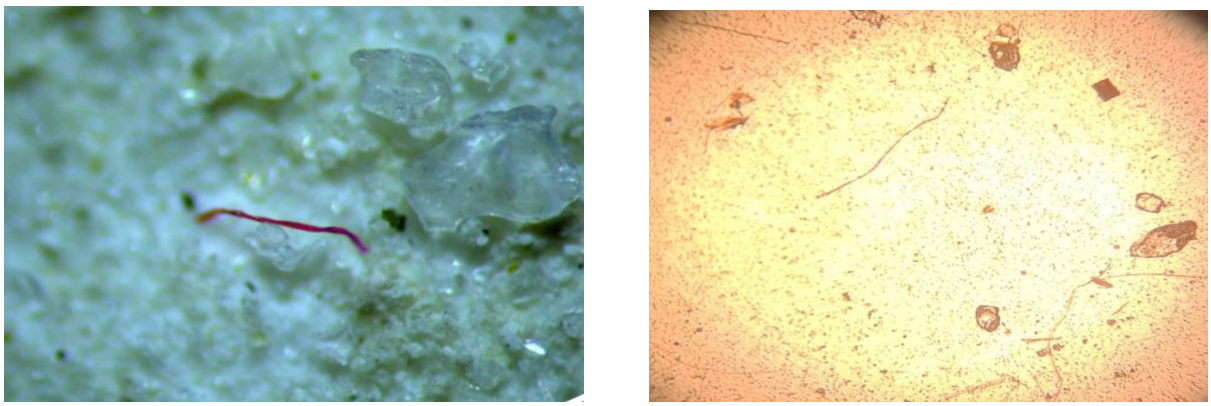
Microplastic A) fibre and B) fibre from A. stutchburyi collected at Ongare Point.

A) **B)**



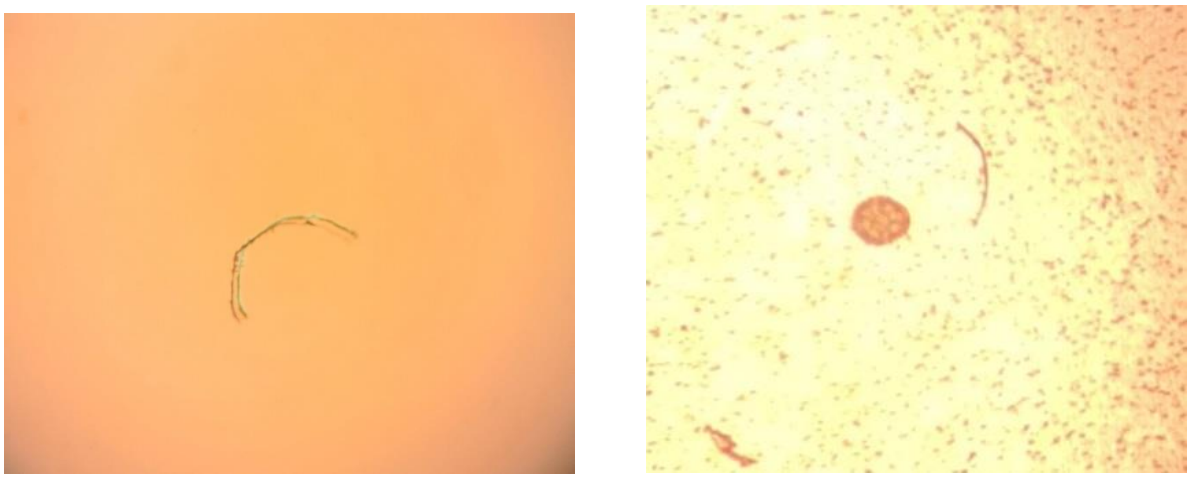
Microplastic A) fibre and B) fragment from M. liliana collected at Rangataua Bay.

A) **B)**



Microplastic A) fibre & fragment and B) multiple fibres from P. subtriangulata collected at Matakana Island sewage outfall.

A) **B)**



Microplastic A) fibre displaying biofauling and B) fibre from M. liliana collected at Otumoetai.