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RISK ASSESSMENT OF MICROPLASTICS IN THE TREATED WASTEWATER DISCHARGE FROM THE NELSON NORTH WASTEWATER TREATMENT PLANT

RISK ASSESSMENT OF MICROPLASTICS IN THE TREATED WASTEWATER DISCHARGE FROM THE NELSON NORTH WASTEWATER TREATMENT PLANT

CARLOS CAMPOS,[1] HAYDEN MASTERTON,[2] OLGA PANTOS,[2]

[1] CAWTHRON INSTITUTE
[2] INSTITUTE OF ENVIRONMENTAL SCIENCE AND RESEARCH LTD

Prepared for Nelson City Council

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Louis Tremblay

APPROVED FOR RELEASE BY:
Grant Hopkins

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EXECUTIVE SUMMARY

Plastic pollution is a worldwide issue due to the mass production and wide-ranging use of these materials and their potential detrimental effects on the environment. Wastewater treatment plant discharges are one of the many sources of plastic pollution to the marine environment. Wastewater treatment processes may not completely remove microplastics (plastic particles < 5 mm in size), hence the importance of quantifying the removal of microplastics at different stages of the treatment process and assessing their fate in discharge-receiving environments.

Nelson City Council contracted the Cawthron Institute and the Institute of Environmental Science and Research Limited (by subcontract) to characterise the concentrations of microplastics in samples of untreated and treated wastewater from the Nelson North Wastewater Treatment Plant (NWWTP), compare the concentrations with those found in other treatment plants and discuss the risks of microplastic contamination to the ecology of Tasman Bay / Te Tai-o-Aorere (hereafter Tasman Bay). This study was undertaken to inform an assessment of environmental effects of the discharge in support of an application for the renewal of the coastal permit (SAR 05-61-01-06), which authorises the discharge of treated wastewater into the bay.

Wastewater samples were taken from the influent screening chamber, oxidation ponds and wetlands on four occasions (two sets of dry-weather and two sets of wet-weather samples). The samples were processed to isolate plastic particles by sieving, oxidation and filtration and subsequently analysed under a stereomicroscope. The types of polymers were identified by Fourier transform infrared spectroscopy-attenuated total reflectance. Each plastic particle was characterised by polymer type, colour, morphotype and length.

Microplastic contamination was found at all stages of the treatment process. Abundance was variable, with the highest concentrations found in influent samples (24.1 ± 13.7 microplastics/L) and the lowest concentrations in treated wastewater samples (2.7 ± 0.7 microplastics/L). The dominant polymer type was polyethylene terephthalate (polyester) (58%), which is widely used in packaging and fabrics. Overall, fibres accounted for 70% of particles, followed by fragments (27.8%), films (2.1%) and microbeads (0.1%). Similar proportions of colourless, black and blue particles were detected between treatment stages (25–27.4%).

Due to differences in sample processing methods, comparisons of these results with mean microplastic concentrations reported in the literature should be considered indicative only. With this in mind, the mean concentration in samples of treated wastewater from the NWWTP (2.7 microplastics/L) is similar to those detected in treated wastewater samples from other New Zealand treatment plants, and some overseas studies have found much higher concentrations (> 50 microplastics/L). Microplastic removal rates could not be determined because sampling intervals were not synchronised with wastewater transit times.

Our study confirms the discharge of microplastic-contaminated wastewater from the NWWTP into Tasman Bay. Due to their small size, microplastics can be ingested by marine species, sometimes when mistaken for food, and can lead to harmful physical effects (chocking, blocked digestive tracts, etc.). Various chemicals are incorporated into plastics as raw materials or additives during manufacture. Consequently, microplastics can introduce toxicity throughout the marine food web and eventually reach humans through bioaccumulation. Microplastic surfaces can also provide habitat for microbial colonisation and biofilm formation, allowing for transport of opportunistic pathogens and invasive species. However, there is insufficient evidence linking microplastic concentrations typically detected in coastal environments and those reported to affect feeding, reproduction and growth of marine organisms.

Despite this, continued efforts to reduce the release of plastic material into the environment should be a priority. This requires a combination of technological solutions, community awareness and behaviour change campaigns, and regulatory measures. New Zealand's Waste Minimisation Act 2008 seeks to reduce waste generation through imposing levies on waste disposed in landfills and supports funding of waste minimisation initiatives. The Act can be used to ban certain plastic products, including the manufacture and sale of products that contain microbeads.

TABLE OF CONTENTS

1. INTRODUCTION 1
1.1. Background 1
1.2. Scope of this report 2
2. SOURCES OF MICROPLASTICS AND THEIR EFFECTS ON THE MARINE ENVIRONMENT 3
3. METHODS 5
3.1. Sample collection 5
3.2. Quality control 5
3.3. Method validation 5
3.4. Sample processing 6
3.4.1. Sieving 6
3.4.2. Wet peroxide oxidation 7
3.4.3. Identification, quantification and analysis 7
4. RESULTS 9
4.1. Abundance of microplastics 9
4.2. Types of polymers 9
4.3. Morphotype, colour and size 10
5. COMPARISON WITH RESULTS FROM OTHER TREATMENT PLANTS 13
6. COMMENT ON THE FATE AND POTENTIAL RISKS OF MICROPLASTIC CONTAMINATION IN TASMAN BAY AND CONTROL MEASURES 15
7. CONCLUSIONS 18
8. ACKNOWLEDGEMENTS 19
9. REFERENCES 20
10. APPENDICES 24

LIST OF FIGURES

Figure 1. Location of the Nelson North Wastewater Treatment Plant discharge in Tasman Bay. 2
Figure 2. Sample processing steps showing sieving (A), wet peroxide oxidation (B), filtration (C) and sample on filter paper ready for analysis (D). 7
Figure 3. Microscope (A) and μ-Fourier transform infrared spectroscopy (B) used to confirm the presence of microplastics in the samples. 8
Figure 4. Mean concentration (± standard deviation) of microplastics found at individual stages of the treatment process. 9
Figure 5. Proportion of polymer types found at individual stages of the treatment process. 10
Figure 6. Morphotypes detected in the wastewater samples. Fragments were rigid and irregular in shape, fibres were long and thread-like, films were thin and transparent, and microbeads were rigid and spherical. 10
Figure 7. Proportions of microplastic morphotypes (left) and colours (right) found at individual stages of the treatment process. 11
Figure 8. Proportion of microplastics falling into six size ranges. 12
Figure 9. Model simulation of plastic particles in the discharge from the Nelson Wastewater Treatment Plant tracked in Tasman Bay for 30 days. 16

LIST OF TABLES

Table 1. Recovery efficiencies of samples spiked with known plastic particles. 6
Table 2. Summary of microplastic concentrations in wastewater samples reported in the literature and data obtained in this study. 14

LIST OF APPENDICES

Appendix 1. Applications of common polymers. 24
Appendix 2. Example spectra of the three most commonly detected microplastics: polyethylene terephthalate (A); acrylic (B); polypropylene (C)... 25

ABBREVIATIONS

EVA	Polyethylene-vinyl acetate
NWWTP	Nelson Wastewater Treatment Plant
PA	Polyamide
PC	Polycarbonate
PE	Polyethylene
PEG	Polyethylene glycol
PET	Polyethylene terephthalate
PHB	Polyhydroxybutyrate
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
PVC	Polyvinyl chloride
PVCA	Polyvinyl chloride acetate

GLOSSARY

Flame retardants	Chemicals that are applied to materials to prevent the start or slow the growth of fire.
Fourier transform infrared spectroscopy (FTIR)	Instrumental technique used to identify the functional groups present in organic and inorganic compounds by measuring their absorption of infrared radiation over a range of wavelengths.
Microplastics	Generic term for small pieces of plastic less than 5 mm in size.
Milli-Q water	Water purified using a Millipore Milli-Q lab water system.
Plasticisers	Chemical additives for making plastics or rubbers softer and more flexible.
Primary microplastics	Microplastics originally manufactured to be that size. Primary microplastics can include, but are not limited to, microbeads as they can also refer to industrial plastic powders and pellets.
Secondary microplastics	Small particle pieces that have resulted from the fragmentation and weathering of larger plastic items.
Zoonotic protozoan parasites	Group of pathogens that are transmitted by the faecal–oral route to humans from other vertebrate animals.

1. INTRODUCTION

1.1. Background

Nelson City Council (NCC) currently holds several resource consents associated with the operation of the Nelson North Wastewater Treatment Plant (NWWTP), including a coastal permit (SAR 05-61-01-06) that authorises the discharge of treated wastewater to Tasman Bay / Te Tai-o-Aorere (hereafter Tasman Bay). This resource consent was granted in 2004 for a duration of 20 years and expires in December 2024.

The NWWTP lies on the seaward, northwest corner of an area of low-lying land in the upper parts of Nelson Haven between Glen Road and what is now Boulder Bank Drive (Figure 1). The plant has been operational since 1979[1] and receives domestic and a small contribution of trade waste flows from the western part of Nelson City, which has a population of approximately 28,200.[2] The treatment process consists of removal of gross solids through the inlet works (screening), pre-treatment of influent flows to reduce biochemical oxygen demand and total suspended solids, pond-based treatment and final polishing through the wetland system prior to discharge into Tasman Bay. The outfall consists of a cement pipe approximately 350 m long, which emerges from the seabed at its offshore end as an 18 m long multiport diffuser in water depth of 11 m (Barter and Forrest 1998).

NCC contracted the Cawthron Institute (Cawthron) and the Institute of Environmental Science and Research Ltd (by subcontract) to quantify the concentrations of microplastics present in wastewater from the NWWTP to support the application and assessment of environmental effects for the renewal of the discharge consent. Our sampling approach targeted three stages of the treatment process: screening, oxidation pond and wetland. We compare the concentrations found with those reported in the literature. We also discuss the risks of microplastic contamination to the ecology of Tasman Bay and contextualise the results with international legislation / guidance.

Microplastics are plastic particles < 5 mm in size. Larger plastic debris (meso- and macroplastics) are outside the scope of our study. Microplastics are usually classified into primary and secondary. Primary microplastics are intentionally manufactured for different applications, including personal care and cleaning products, and pre-production pellets for fabrication of other plastic goods. Secondary microplastics are plastic particles that originate from the breakdown of larger particles by photolytic, mechanical and biological processes (Iyare et al. 2020). The wastewater network in the Nelson catchment is likely to collect mostly primary microplastics in their intact form .

[1] The oxidation pond was commissioned in 1979. A marine outfall existed to discharge untreated wastewater from Nelson City and satellite settlements at the northeastern end of the Boulder Bank from 1968.
[2] Population equivalent estimated for 2020. The plant is also designed to treat flows for a population equivalent of 33,750 in 2050 (Cordell and Setiawan 2007).

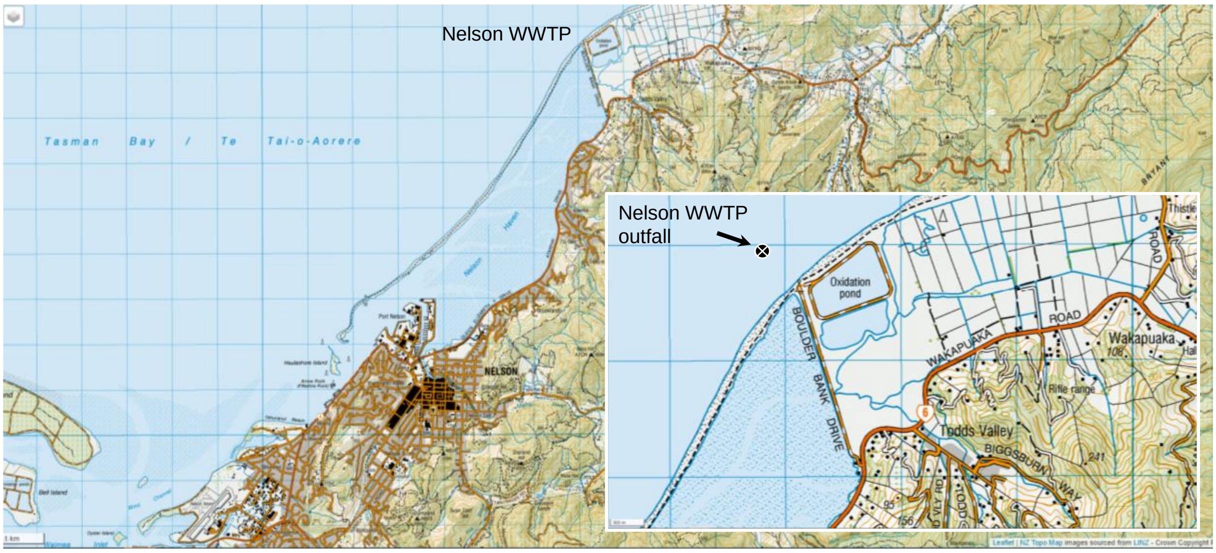

Figure 1. Location of the Nelson North Wastewater Treatment Plant discharge in Tasman Bay. Source: NZ TopoMap©.

1.2. Scope of this report

According to Policy 23 of the New Zealand Coastal Policy Statement 2010, in managing wastewater discharges to the coastal environment, consideration must be given to the nature of the contaminants discharged, the capacity of the receiving environment to assimilate the contaminants, and avoidance of significant adverse effects on ecosystems and habitats after reasonable mixing (Department of Conservation 2010). To meet these requirements, we structured our report as follows:

- **Section 2** presents a brief overview of the sources of microplastics and their effects on the marine environment.
- **Sections 3 and 4** describe sample collection and laboratory testing methods and present the results of microplastics quantified in samples of wastewater from the NWWTP.
- **Section 5** compares the concentrations of microplastics detected in NWWTP samples with those detected in samples from other treatment plants in New Zealand and overseas.
- **Section 6** comments on the potential risks of microplastic contamination in the discharge-receiving environment (Tasman Bay) associated with the NWWTP discharge and control measures to mitigate the risks.

2. SOURCES OF MICROPLASTICS AND THEIR EFFECTS ON THE MARINE ENVIRONMENT

Plastics are ubiquitous in the environment. Plastic waste can originate from different sources and thus occur in different shapes and sizes. Plastic debris has been classified according to size into macroplastics, mesoplastics, microplastics and nanoplastics, but different definitions have been proposed for each category. Microplastics are the focus of this report and are estimated to account for approximately 92% of global plastic counts (Eriksen et al. 2014). They include a wide array of materials and originate from many applications (listed in Appendix 1). Microplastics are specifically designed to be durable, are highly persistent and can be easily transported over long distances.

Municipal wastewater treatment plant discharges are important routes for microplastics to enter the marine environment (Ziajahromi et al. 2016). Other, equally important, routes include land run-off, river discharges and atmospheric deposition. Wastewater treatment plants cannot be expected to fully remove microplastics because most treatment processes are not designed to do so. Loadings and removal efficiencies vary considerably between treatment plants. However, average removal rates > 90% have been reported in many studies (e.g. Simon et al. 2018; Hidayaturrahman and Lee 2019; Iyare et al. 2020). The majority of plastics entering treatment plants are concentrated and retained in the sludge and, ultimately, biosolids. Despite these high removal rates, large amounts of microplastics are still discharged to the environment daily (Murphy et al. 2016; Ruffell et al. 2021).

The density of individual polymer types can influence the fate of microplastics in aquatic environments. In sea water, higher-density particles (> 1.02 g/cm^3) sink to the sea floor and accumulate in sediments, while lower density particles tend to float on the sea surface or in the water column (van Cauwenberghe et al. 2015). Due to their constant fragmentation, microplastics are bioavailable to some of the smallest marine biota, such as zooplankton, as well as the largest marine megafauna, such as marine mammals. Filter-feeding organisms, such as bivalves, can also ingest microplastics; particle size and shape as well as surface properties on capture, ingestion, sorting and egestion have been subject to much study (Ward et al. 2019). Relatively few studies have assessed microplastics in the environment within the 10–50 µm size range because this range typically falls below the limit of resolution of most equipment for analysis. However, researchers are continuously expanding their analytical techniques to detect and identify ever smaller micro- and nanoplastics.

Microplastics are contaminants of emerging concern because they are potentially harmful to wildlife and humans. Harmful effects are caused by three main mechanisms: obstruction due to physical uptake of plastic particles, adsorption and absorption of chemicals released in the environment, and release of chemical additives (Barrick et al. 2021). Their wide distribution in the marine environment poses a threat / risk to marine organisms, which can mistake these particles as food based on their colour and size, or feed indiscriminately on them. Examples of physical harm from plastic ingestion include choking and blocked digestive tracts (Derraik 2002). Microplastics can also contain toxic substances added during manufacturing, such as flame retardants, plasticisers and pigments (these substances have been quantified in samples of treated wastewater from the NWWTP and results are presented in a companion report; Northcott et al. 2022). The hydrophobic surfaces of microplastics can also act as a vector for the uptake of, and exposure to, numerous classes of emerging organic contaminants. However, there is little information on sorption and leaching of these contaminants from plastics, and most data on toxicity derives from laboratory studies.

There is also potential for microplastic surfaces to provide habitats for microbial colonisation and biofilm formation, allowing for migration of opportunistic pathogens and invasive species. The association between zoonotic protozoan parasites (*Toxoplasma gondii*, *Cryptosporidium parvum*, *Giardia enterica*) (Zhang et al. 2022) and bacterial pathogens (vibrios) (Bowley et al. 2021) with microplastics in the marine environment has been increasingly reported.

3. METHODS

3.1. Sample collection

Samples of wastewater were taken on four occasions in 2022 from three stages of the treatment process operating at the NWWTP: influent screening chamber, oxidation ponds and wetlands. Samples collected on 22 June and 26 October were taken in dry weather, and samples collected on 14 July (43 mm)[3] and 13 September (5.5 mm) were taken in wet weather.

Samples (2 L) were collected at four time intervals 2 hours apart throughout the day, with approximately 15 minutes between collections from each site. Each of the four time-point samples from a site was combined in two 4 L pre-washed amber glass bottles (a total of 8 L of wastewater per site). All samples were collected by Nelmac personnel (on behalf of NCC) following a sampling protocol and delivered by overnight courier to the Institute of Environmental Science and Research in Christchurch. Once received, samples were stored at 4 °C until analysis.

3.2. Quality control

Procedural blanks were carried out to account for possible environmental contamination originating from the sampler's clothing, atmospheric deposition or sampling equipment. Approximately 2 L of Milli-Q water was poured into pre-washed amber glass bottles at each sampling site and time point to simulate wastewater collection.

All work was carried out under controlled conditions to minimise contamination throughout sample processing. All benchtops and fume hood surfaces were wiped with 70% ethanol (v/v) before and between each step and sample. All glassware and equipment were washed with soap and tap water and rinsed with ultrapure water, followed by a final rinse with acetone. Once cleaned, all glassware and equipment were covered with aluminium foil. While samples were open and processed in the fume hood, a wetted filter paper was left exposed as an environmental blank to determine contamination within the laboratory.

3.3. Method validation

To determine the isolation / recovery efficiency of microplastics from the sample matrix, a total of seven procedural blanks and four samples were each spiked with 24 plastics (polypropylene, polystyrene, polyamide and polyethylene) in the range of 100–

[3] Total cumulative rainfall 3 days prior to sampling. Data from: https://www.tasman.govt.nz/my-region/environment/environmental-data/rainfall/report

1,000 µm. The number of spikes was counted post-sample processing. Isolation efficiency for each size for all polymer types was 93.8% (500–1,000 µm), 100% (300–500 µm) and 81.3% (100–300 µm) (Table 1).

Table 1. Recovery efficiencies of samples spiked with known plastic particles.

Polymer colour	**Size range (µm)**	**Average number of plastic spikes retained over four sampling points**		**Recovery (%)**
		Procedural blanks (*n* = 7)	Samples (*n* = 4)	
High-density polyethylene (orange)	500–1,000	1.9	2.0	95.8
	300–500	2.0	2.0	100
	100–300	1.7	1.8	84.2
High-impact polystyrene (purple)	500–1,000	2.0	2.0	100
	300–500	1.7	1.8	84.2
	100–300	1.7	1.8	86.7
Polyamide (green)	500–1,000	2.0	1.8	95.8
	300–500	1.9	2.0	95.8
	100–300	2.0	1.5	91.7
Polypropylene (pink)	500–1,000	2.0	2.0	100
	300–500	1.9	2.0	95
	100–300	1.8	1.3	61.7

3.4. Sample processing

The two 4 L bottles from each time-point / sampling site were combined before processing. Samples and procedural blanks were processed using the same methods.

3.4.1. Sieving

The liquid fraction from the samples was removed using a sieve stack consisting of four sieves: 1,000 µm, 300 µm, 50 µm and 20 µm. Each sieve's contents were rinsed using ultrapure water into individual 500 Ml Schott bottles with a stainless-steel funnel (Figure 2).

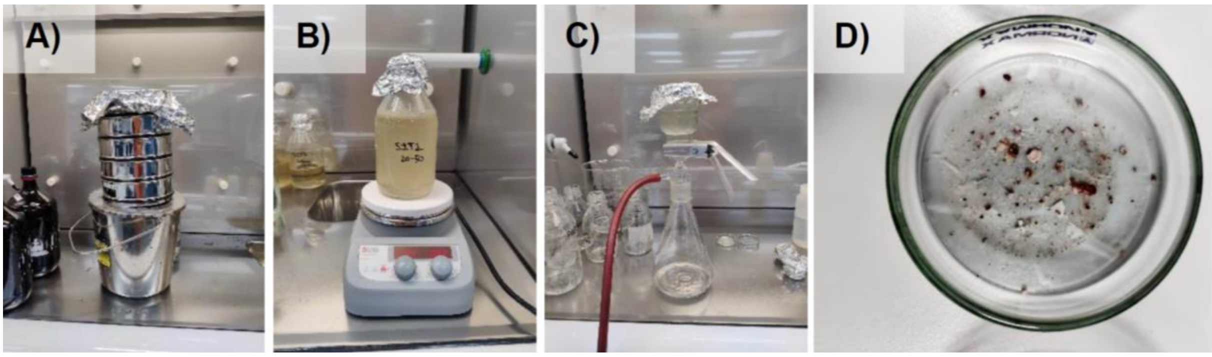

Figure 2. Sample processing steps showing sieving (A), wet peroxide oxidation (B), filtration (C) and sample on filter paper ready for analysis (D).

3.4.2. Wet peroxide oxidation

Wet peroxide oxidation was performed to digest the organic matter present in the sample while keeping the plastic unaltered. Aqueous iron (II) sulphate solution (20 Ml, 0.05 M) and hydrogen peroxide (20 Ml, 30%) was added to each Schott bottle (Figure 2B). Bottles were heated to 50 °C. Once the digestion ceased, another 20 Ml of 30% hydrogen peroxide was added if organic matter was still present. Once all the organic matter was digested, the contents of the Schott bottles were allowed to cool to room temperature and filtered directly onto 10 µm polycarbonate filters (ø = 4.7 mm) (Figure 2C–D). The filters were placed in glass Petri dishes with lids and oven-dried at 40 °C overnight.

3.4.3. Identification, quantification and analysis

Filter papers were examined under a Leica M125 microscope (magnification 8–100×) (Figure 3A). All suspected microplastics were picked out with tweezers and placed onto a calcium fluoride (CaF_2) disc. The plastics were photographed with a mounted Leica MC170 digital camera, measured, and characterised based on morphology (fibre, fragment, film and microbead), colour and size. Each particle was analysed by µ-Fourier transform infrared spectroscopy (Mftir; PerkinElmer Spectrum 2, with Spotlight 200i microscope) (Figure 3B). Particles were scanned at a resolution of 4 cm^{-1}, a scan speed of 1 cm s^{-1} and a spectral wavelength range of 990–4,000 cm^{-1}. The resulting spectra were compared against a series of pre-loaded polymer spectral reference libraries to identify the polymer type. Spectra required a database hit of > 75% to be accepted. Hits < 75% were reviewed manually, checking characteristic peaks, or reanalysed using a diamond compression cell.

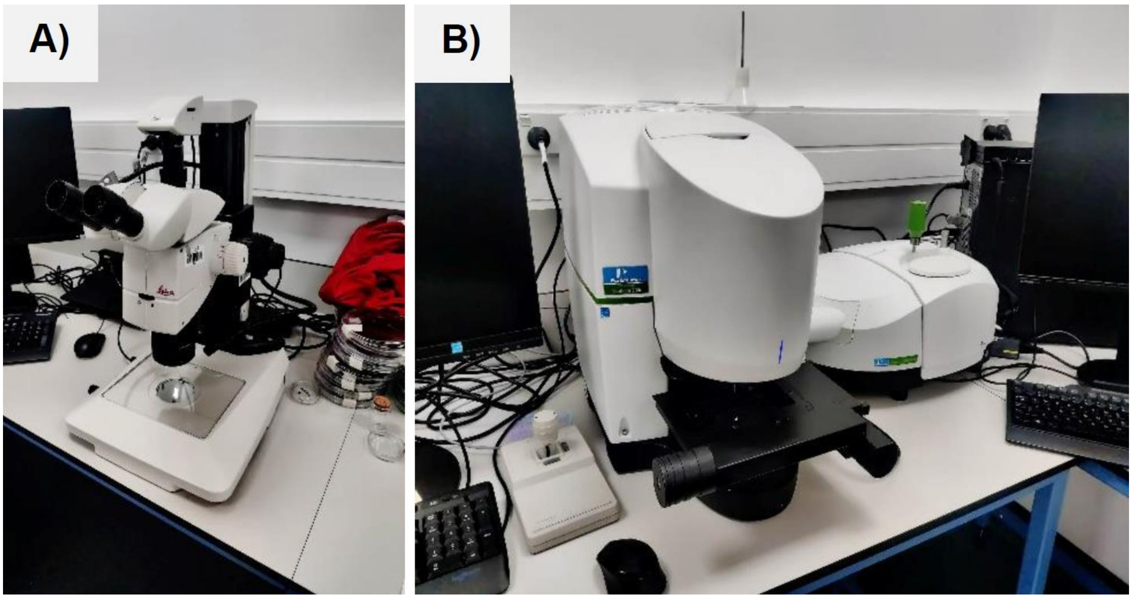

Figure 3. Microscope (A) and µ-Fourier transform infrared spectroscopy (B) used to confirm the presence of microplastics in the samples.

Controls

Environmental and procedural blanks were analysed as described above. The four environmental blanks had an average of 1.5 ± 1.9 microplastics, which were generally clear polyethylene terephthalate (PET) fibres. There were 12 procedural blanks with an average of 10.7 ± 6.3 microplastics. The contamination observed in the procedural blanks is likely due to contamination via air deposition during sampling. Microplastics in the procedural blanks were generally clear PET fibres or polypropylene (PP) fragments, but these were at much lower concentrations than in the samples. The number of microplastics in the procedural blanks with the same polymer type, morphotype and colour was subtracted from the corresponding sample for each time point.

4. RESULTS

4.1. Abundance of microplastics

Microplastics were present in the three tested stages of the wastewater treatment process. Mean concentrations varied across the treatment process (Figure 4), with the highest mean concentration detected in the influent screening chamber (24.1 ± 13.7 microplastics/L), followed by oxidation ponds (3.3 ± 1.8 microplastics/L) and wetlands (2.7 ± 0.7 microplastics/L). We were not able to estimate reduction rates at each treatment step because the time between samples taken from each site was approximately 15 minutes, which is much shorter than the expected retention time within the treatment plant (the designed retention time in the pond is < 10 days). Therefore, it cannot be assumed that the same body of water was sampled.

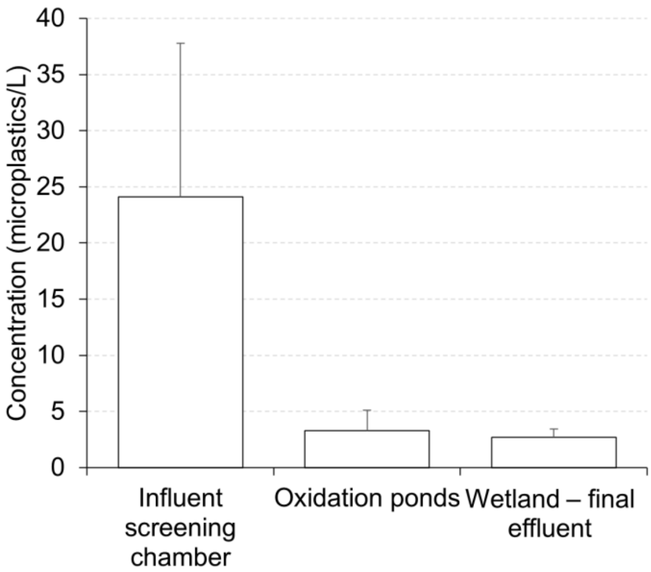

Figure 4. Mean concentration (+ standard deviation) of microplastics found at individual stages of the treatment process.

4.2. Types of polymers

In total, 22 types of polymers were identified. These include acrylic, polyethylene (PE), PET, PP, polyamide (PA), polyurethane (PU), poly(acrylate:styrene), polystyrene (PS), poly(styrene:butadiene), polyisoprene, acrylic polyester copolymer, polyvinyl chloride (PVC), polyethylene-vinyl acetate (EVA), polyoxyethylene, polyterpene, polyvinyl chloride acetate (PVCA), polycarbonate (PC), polynorbornene, polyamide-imide, epoxy, polyhydroxybutyrate (PHB) and polyethylene glycol (PEG).

The dominant polymer type was PET (58%), followed by acrylic (19.7%), PP (11.8%), PE (4.7%) and PA (1.3%) (Figure 5). The remaining polymer types account for < 1%. Example spectra of three commonly detected polymers (PET, acrylic and PP) are presented in Appendix 2.

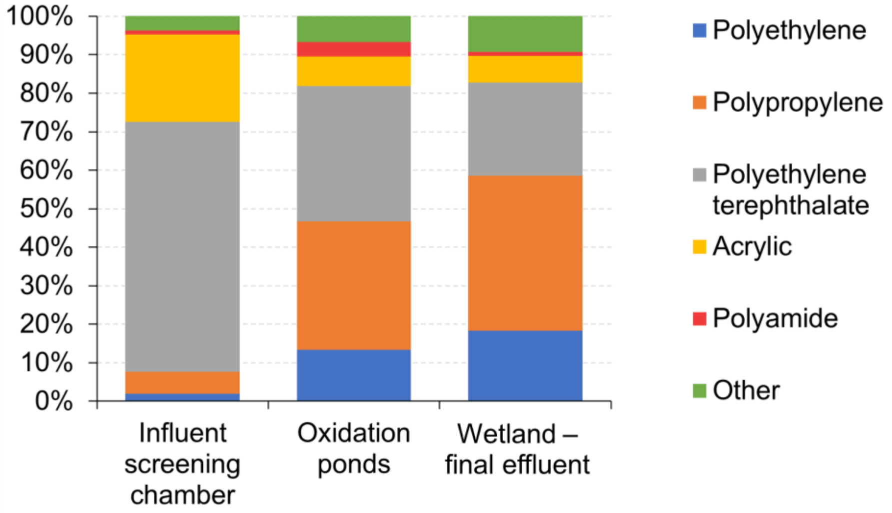

Figure 5. Proportion of polymer types found at individual stages of the treatment process.

4.3. Morphotype, colour and size

Four different morphologies of microplastics were identified in the samples: fibres (70%), fragments (27.8%), films (2.1%) and microbeads (0.1%) (Figure 6).

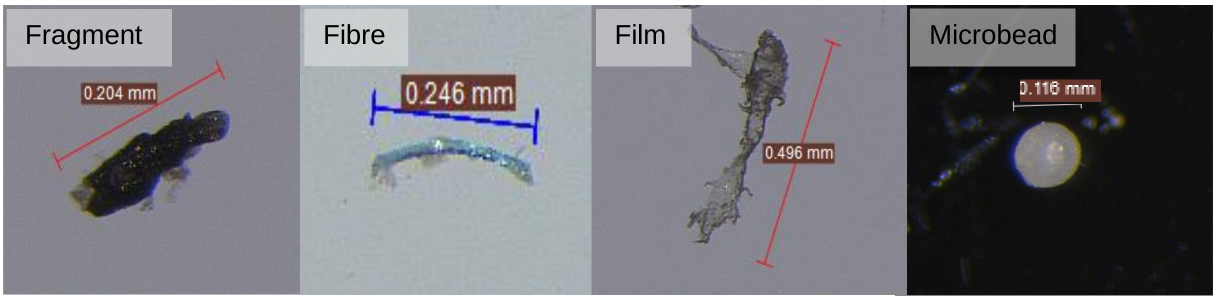

Figure 6. Morphotypes detected in the wastewater samples. Fragments were rigid and irregular in shape, fibres were long and thread-like, films were thin and transparent, and microbeads were rigid and spherical.

The influent screening chamber samples were dominated by fibres (76.8%), followed by fragments (22.7%) and films (0.5%) (Figure 7). Samples taken from the oxidation pond had the same proportion of fibres and fragments (47.6%), with films accounting for 4.76% of microplastic particles. Samples taken from the wetlands had more fragments (49.4%) than fibres (36.8%), 12.6% were films and this was the only site where microbeads were detected (1.1%). Samples taken from the ponds and wetland had greater proportions of colourless microplastics than those from the influent chamber (Figure 7).

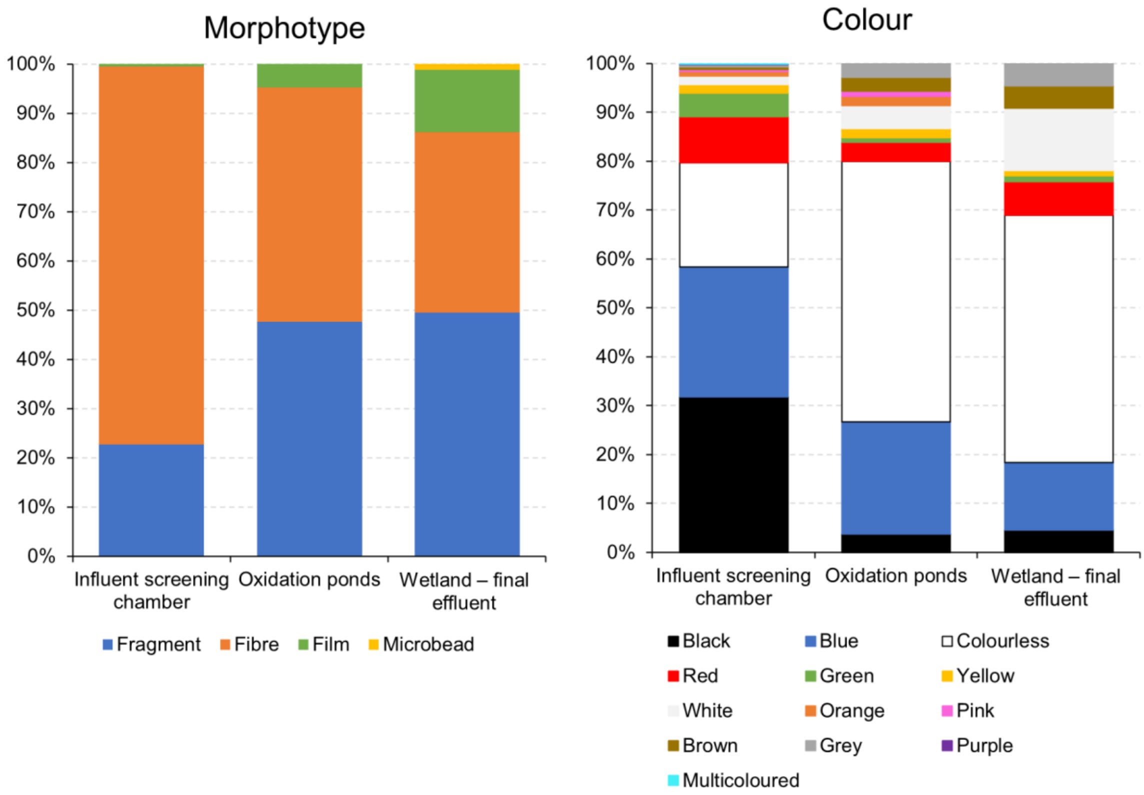

Figure 7. Proportions of microplastic morphotypes (left) and colours (right) found at individual stages of the treatment process.

Overall, particle sizes in the samples ranged from 20 µm–9,494 µm. The dominant size range was 300–1,000 µm (39.6%), followed by 100–300 µm (28.1%) and 1,000–5,000 µm (22%). Samples of influent followed this same trend: 300–1,000 µm > 100–300 µm > 1,000–5,000 µm. However, samples from the ponds and wetlands were dominated by particles in the 100–300 µm range (45.5% and 48.6%, respectively) (Figure 8).

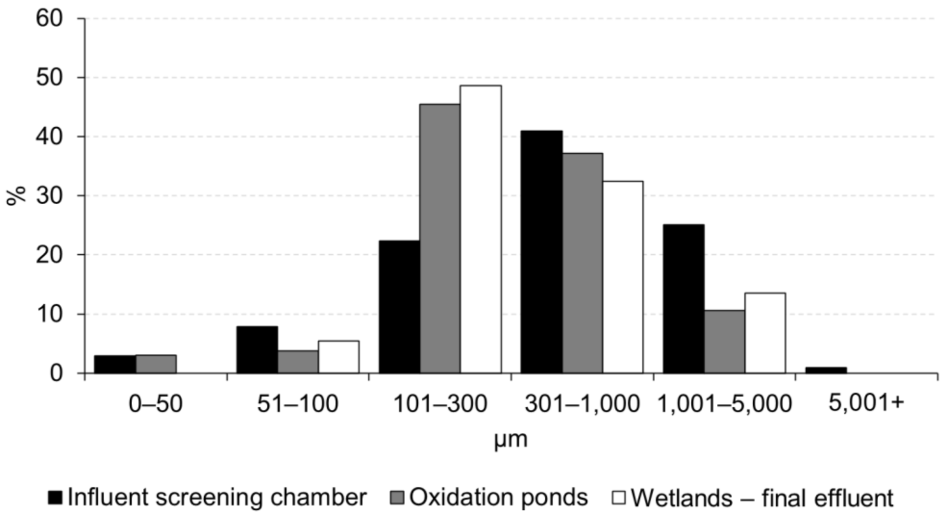

Figure 8. Proportion of microplastics falling into six size ranges. Data presented are uncorrected due to length not affecting blank corrections.

5. COMPARISON WITH RESULTS FROM OTHER TREATMENT PLANTS

Summary data on microplastic concentrations in wastewater reported in the international literature are presented in Table 2. Methods for sampling and quantification vary between studies, which challenges comparison of results. Automated sampling significantly increases sample volumes compared to grab sampling approaches, such as that used in our study. Most studies reviewed used a combination of visual and FTIR techniques for microplastic characterisation. No apparent relationship exists between the reported concentrations and wastewater treatment level / population equivalent.

Overall, microplastics are commonly detected in both untreated and treated wastewater samples. Reported concentrations in untreated wastewater ranged between 1 and 10,044 microplastics/L, while those in treated wastewater ranged between 0 and 447 microplastics/L. The results obtained in NWWTP samples appear to be similar to those obtained in other New Zealand treatment plants. It should be stressed that the method used in our study is similar to that used by Ruffell et al. (2021), and therefore the results are directly comparable.

The most common polymers detected in overseas studies are polyester, PE, PET and PA, with fibres accounting for the largest fraction of the observed microplastics in the classification of different shapes (Sun et al. 2019). The proportions of polymer types and morphotypes are not markedly different from those identified in NWWTP samples, although in our study fragments represent approximately 50% of the particles in samples of treated wastewater, while Sun et al. (2019) reported an average of 29% for this morphotype (data from all studies combined). Sun et al. (2019) also reported that secondary treatments tend to remove more fragments than fibres, which suggests that the process at the NWWTP may not be particularly effective in removing this morphotype.

In NWWTP samples, we found an increase in the proportion of fragments from untreated (23%) to treated (49%) wastewater. This difference could be associated with fragmentation of larger particles during the treatment process rather than high concentrations of this morphotype arriving at the plant. In contrast, the proportion of fibres reduced from 77% to 37%, which indicates higher loadings arriving at the plant (possibly associated with washing machine effluent) and removal of this morphotype during the treatment process (possibly through de-sludging). However, based on current evidence it is not possible to establish obvious connections between morphotypes (fragments versus fibres) and specific marine ecological effects.

Table 2. Summary of microplastic concentrations in wastewater samples reported in the literature and data obtained in this study. Most data in the table were compiled and analysed by Sun et al. (2019). (Grab sampling by container; n/r = data not reported.)

Country	Wastewater treatment level	Population equivalent	Sampling method	Detection method	Untreated wastewater (microplastics/L)	Wastewater discharge (microplastics/L)	Reference
Sweden	Secondary	12,000	Grab	Visual/FTIR	15	0.008	Magnusson & Norén (2014)
France	Secondary (biofilter)	800,000	Autosampler	Visual	293	35	Dris et al. (2015)
USA	Secondary	n/r	Pump	Visual/FTIR	1	0.0008	Carr et al. (2016)
Scotland	Secondary	650,000	Grab	Visual	16	0.25	Murphy et al. (2016)
Netherlands	Secondary	13,000	Grab	Visual	68–910	55–81	Leslie et al. (2017)
Australia	Tertiary (reverse osmosis)	15,000	Pump	Visual/FTIR	n/r	0.21–0.28	Ziajahromi et al. (2017)
Australia	Secondary	67,000	Pump	Visual/FTIR	n/r	0.4	Ziajahromi et al. (2017)
Denmark	Secondary	n/r	Autosampler, grab	FTIR	2,223–10,044	29–447	Simon et al. (2018)
USA	Tertiary (biological aerated filter)	12,000	Pump	Visual	n/r	0.009	Mason et al. (2016)
Germany	Tertiary (maturation pond)	11,000–210,000	Pump	FTIR	n/r	0.01–0.38	Dubaish & Liebezeit (2013)
USA	Tertiary (granular filter)	9,900	Grab	Visual	91	2.6	Michielssen et al. (2016)
Finland	Tertiary (biological aerated filter)	800,000	Pump	Visual	610	13.5	Talvitie et al. (2016)
New Zealand	Tertiary (UV disinfection)	3,000	Autosampler	Visual/FTIR	n/r	1.8	Ruffell et al. (2021)
New Zealand	Tertiary (oxidation pond)	377,000	Autosampler	Visual/FTIR	n/r	1.2	Ruffell et al. (2021)
New Zealand	Tertiary	30,250	Autosampler	Visual/FTIR	n/r	0.8	Ruffell et al. (2021)
New Zealand	Tertiary (wetland)	33,750	Autosampler	Visual/FTIR	24	2.7	This study

6. COMMENT ON THE FATE AND POTENTIAL RISKS OF MICROPLASTIC CONTAMINATION IN TASMAN BAY AND CONTROL MEASURES

The fate of microplastics in coastal waters is influenced by the density of individual polymer types. Higher-density particles (PET, PVC, PS) sink to the sea floor and can accumulate in sediments, while lower density particles (PP, PE) float on the surface or remain suspended in the water column and may travel considerable distances. Polymers then disintegrate by photo-oxidative degradation mediated by ultraviolet radiation. Treated wastewater from the NWWTP is discharged to Tasman Bay, a dynamic open-coast environment. Factors controlling the transport and sedimentation of microplastics in these types of coastal environments include winds, tides, currents, bathymetry, temperature and salinity variations in the water column and type of substratum.

A study in Sweden modelled the transport and deposition of three types of polymers (PE, PP and PET) in the Baltic Sea from different types of discharges (wastewater treatment plant discharges, combined sewer overflows, other discharges of untreated wastewater) (Schernewski et al. 2020). Their results indicated that most microplastics are not transported over very long distances and are washed ashore soon after discharge. The highest particle accumulations were found on the shores of semi-enclosed or enclosed waterbodies (fjords and embayments), which serve as sink and retention environments for microplastics and protect the open sea from pollution. The study also found that microplastics that sink to bottom sediments stay there for only weeks or a few months. Many particles are washed ashore after storm events due to wave-induced resuspension and subsequent accumulation on the coast.

Cawthron has developed the web-based Ocean Plastic Simulator,[4] which combines a regional 3D model of tides, winds and currents for the Cook Strait and Marlborough Sounds with a 'particle tracking' Ocean Tracker model and maps to simulate the path taken by plastics in the top 3 m of the sea (Vennell et al. 2021). A simulation of plastic particles released at the NWWTP discharge location over 30 days shows connectivity between the discharge point and the stretch of coast extending to Pepin Island / Delaware Bay and into the approaches to Croisilles Harbour (Figure 9). While this model output shows only one timeframe / weather condition, it provides an indication of the potential pathways and receptors in the area affected by the discharge. Particle releases over longer timeframes may extend further south. Species inhabiting this area and potentially vulnerable to plastic contamination from the discharge include pelagic fish (see detailed discussion of finfish species and fisheries in Morrisey and Campos 2023 [forthcoming]) and marine mammals (see risk assessment by Clement and Campos 2022).

[4] https://oceanplasticsim.cawthron.org.nz/

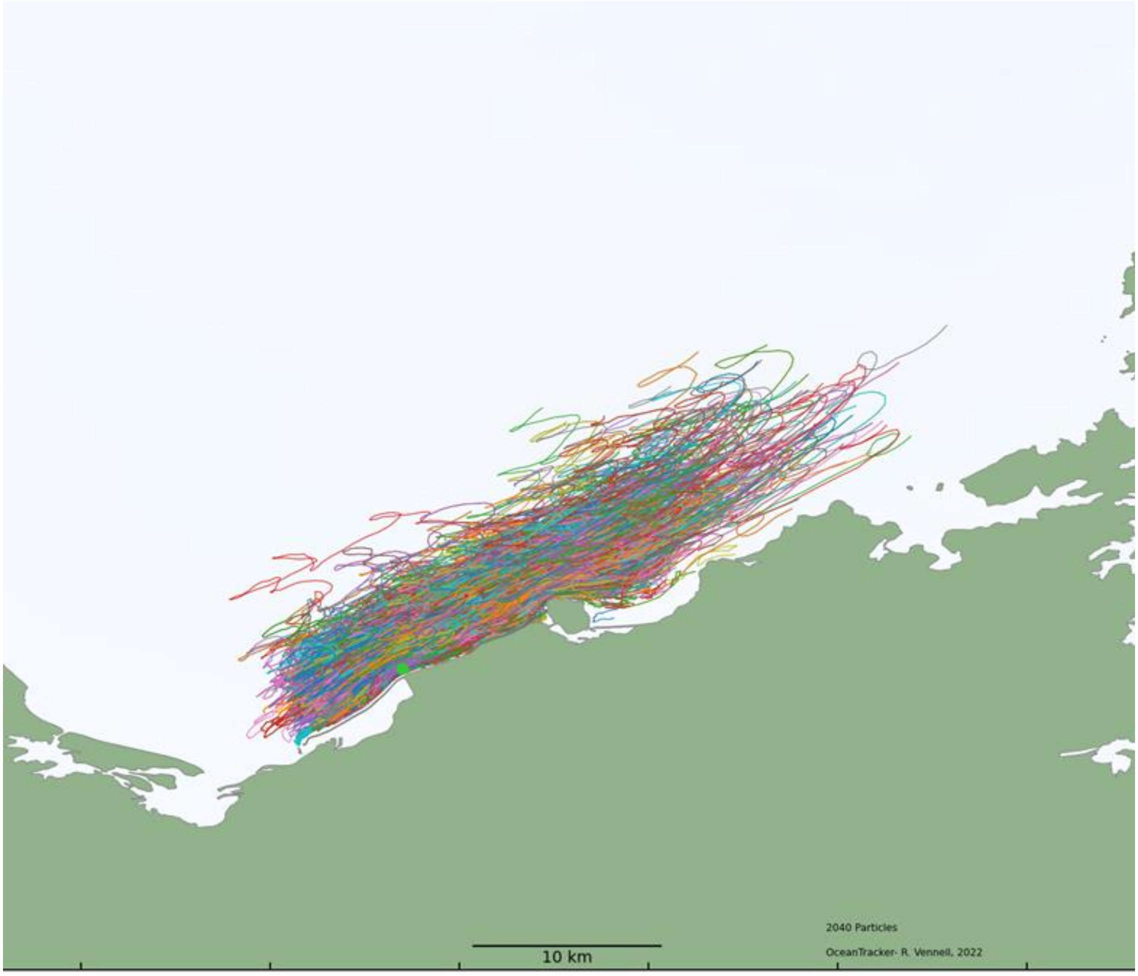

Figure 9. Model simulation of plastic particles in the discharge from the Nelson North Wastewater Treatment Plant tracked in Tasman Bay for 30 days. For further details on this model, see Vennell et al. (2021). The light green dot shows the location of the NWWTP discharge.

An increasing number of studies are identifying and quantifying microplastics in marine organisms worldwide. In New Zealand, microplastics have been found in the Greenshell™ mussel / kūtai (*Perna canaliculus*; Webb et al. 2019), and in the stomach contents of a wide range of marine fishes (Horn 2021) and stranded common dolphins (Stockin et al. 2021). A risk assessment to determine the dietary threats associated with microplastics in the environment commissioned by the Ministry for Primary Industries reviewed contamination data for marine species (finfish, molluscs, crustaceans, other marine invertebrates, seabirds) and concluded that, currently, risks to consumers cannot be determined due to lack of data on plastic contamination in processed food and food species, and poor understanding of the fate of plastics following ingestion by humans (Pantos et al. 2019).

In New Zealand, there is no statutory instrument regulating the release of (micro)plastics from wastewater discharges to aquatic environments. Tremblay et al. (2019) reviewed current overseas guidelines, legislation and initiatives to reduce or eliminate plastics and provided recommendations for more effective management of environmental microplastic contamination. They commented that a multifaceted approach is required in New Zealand, comprising technological solutions (e.g. development of alternatives to petrochemical-based plastics, provision of filters in washing machines, interception and capture in stormwater), community awareness and behaviour change campaigns, and better policies and regulations. Concerning the latter, the Waste Minimisation Act 2008 already provides a mechanism for reducing plastic waste in landfills by imposing levies. The Act provides for stewardship recycling schemes to eliminate plastic-based materials used in agriculture and horticulture. The New Zealand Government is seeking to deliver on its promise to phase out problem plastics (food and drink packaging made from PVC and PS that is hard to recycle, and single-use plastic items) by July 2025 (New Zealand Government 2021).

7. CONCLUSIONS

- Wastewater samples taken from three stages of the treatment process at NWWTP were contaminated with microplastics. Data on concentrations, morphotypes, types of polymer and colours are presented. The highest mean concentration of microplastics was 24.1 ± 13.7 microplastics/L in influent samples, and the lowest was 2.7 ± 0.7 microplastics/L in wastewater collected from the wetland, the last stage prior to discharge into Tasman Bay. The concentrations in the NWWTP discharge are within the range of those reported in the literature, although methods of quantification differ considerably between studies and therefore comparisons should be made with caution.

- Fibres (70%) were the dominant morphotype detected. Colourless (27.4%), black (26.3%) and blue (25%) were the predominant colours. PET (also known as polyester) was the most commonly detected polymer (58%), followed by acrylic (19.7%), PP (11.8%) and PE (4.7%). These results are consistent with those found in other wastewater treatment plants.

- Upon discharge into Tasman Bay, these microplastics can travel considerable distances when suspended in the water column or settle to the sea floor, where they remain for weeks or even months and may be resuspended during stronger currents or following storm events. Heavier microplastics such as PVC and PET are more likely to sink and be ingested by benthic organisms. Some marine animals are indiscriminate feeders that ingest anything in the appropriate size range. Others use visual and chemical cues for finding and selecting food, and therefore ingestion of microplastics by these animals is more complex.

- Microplastics have been found in a diversity of New Zealand marine species. These materials can have an impact on marine organisms at many levels, but this remains poorly studied. Microplastics can also be a source and sink of chemicals / toxicants to organisms, and they can provide habitat for pathogens and invasive species. Given the lack of baseline data, it is not possible to assess the ecological risks from microplastics to marine communities in Tasman Bay. Such ecological risk assessment would require more information on the fate and transport of the microplastics within the receiving environment and accumulation in biota.

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10. APPENDICES

Appendix 1. Applications of common polymers.

Polymer	Examples of use
Polypropylene	Packaging, toys, household appliances, lighting diffusers, CD cases, fishing lines
Polyethylene	Packaging, plastic bags, bottles
Polystyrene	Packaging, household appliances, consumer electronics, disposable medical items, building and construction
Polyamide	Textiles, fishing lines, carpets, food packaging
Polycarbonate	Bottles, CDs and DVDs, food containers, eyeglass lenses
Polyester	Textiles, ropes, insulation, plastic bottles
Polyvinyl chloride	Building products, piping, coatings, low-voltage insulation, packaging, medical and leisure products
Polyethylene terephthalate	Packaging (including food and beverages), fabrics, films to moulded parts for automotive, electronics

Appendix 2. Example spectra of the three most commonly detected microplastics: polyethylene terephthalate (A); acrylic (B); polypropylene (C).