1-29-2024 2:30 PM

Controls on Plastic Debris Capture in Urban Stormwater Drains of London, Canada: A Study Within the Great Lakes Watershed

Nina Kozikowski,

Supervisor: Patricia, Corcoran, *The University of Western Ontario*

A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Geology

Recommended Citation

Kozikowski, Nina, "Controls on Plastic Debris Capture in Urban Stormwater Drains of London, Canada: A Study Within the Great Lakes Watershed" (2024). *Electronic Thesis and Dissertation Repository*. 9928.
https://ir.lib.uwo.ca/etd/9928

Abstract

Land-based sources are the greatest contributors of plastic pollution in aquatic environments. Prior to this investigation, there were no available studies concerning the number and types of plastic debris items between 1 mm and 5 mm captured in urban stormwater drains. The present study examined macroplastic (>5 mm) and large microplastic (1-5 mm) debris that accumulated in LittaTrap^{TM} devices at six drain sites over four seasonal periods in London, Ontario, Canada. Macroplastics (MaPs) and microplastics (MPs) were found in all 36 samples, and the totals ranged from 5-158 MaPs and 18-359 MPs per trap. Out of the 118 different MaPs found, the most common were cigarette butts, wrappers, and expanded polystyrene. The predominant MPs were fragments, foams, and fibres. Summer samples contained the highest average amounts of plastic. The main controls on plastic debris accumulation in stormwater drains of the London core are increased pedestrian traffic, driving, and seasonal variability.

Keywords

Macroplastic; Microplastic; Stormwater Drains; Urban; London, ON; Great Lakes Watershed

Summary for Lay Audience

The global input of plastic debris into the natural environment is mainly sourced from land-based activities. Within urban areas, plastics generated through littering, accidental spillage, and degraded infrastructure, accumulates on city streets and other impervious surfaces. During rain events, these plastic items run off into stormwater drains and eventually become deposited in natural tributaries. This study examines the possible controls on plastic debris deposition into stormwater drains of London, Ontario, Canada. Six LittaTrap^{TM} devices were installed in city core stormwater drains to capture macroplastic (> 5mm) and large microplastic (1-5 mm) debris during different seasons before entering the watershed. Macroplastics (MaPs) and microplastics (MPs) were found in all 36 samples, and were characterized according to abundance, size, item type, and composition. The results indicate a seasonal influence on number of items, as the winter samples on average contained the fewest plastics overall. Total precipitation and average wind speed, however, did not correlate with the amounts of plastic debris at each location. Instead, increased plastic pollution appears to be linked to increased outdoor activities during the warmer months. Plastic debris abundances also showed a positive correlation with stormwater drain location, as the highest counts were in high pedestrian areas. The three most common identifiable MaPs were cigarette butts (31.4%), wrappers (18.3%), and expanded polystyrene (3.5%). In terms of applications, "smoking", "packaging", and "narcotics" were most prevalent, with the latter category most common at the site where individuals were witnessed using and distributing narcotics. Fragments were the most common type of MPs, accounting for 45.0% of the total. Polymer compositions, as determined by Fourier transform infrared spectroscopy (FTIR) and a visual identification method, were mainly polyethylene and polypropylene, which are common to a large variety of products. Other polymer types, such as polybutadiene, alkyds, and polyethylene terephthalate are consistent with rubber, paints, and textiles, respectively. This study reveals that location within the downtown core is a key driver of plastic debris amounts and types, which emphasizes the urgent need for public awareness campaigns regarding land-based plastic use, fate, and reduction.

Acknowledgments

First and foremost, I would like to thank Dr. Patricia Corcoran for her unwavering support and academic guidance throughout the entirety of my thesis. Your knowledge, support, kindness, and friendship have not only greatly influenced my academic journey but also positively contributed to my personal growth. The opportunity to collaborate with you and the team has been an extremely rewarding experience. Thank you to Patrick Donnelly and Brad Weber from the City of London, for helping initiate the beginning stages of this project and for support throughout my research. I am also extremely grateful to Barry Orr from the City of London for all of his assistance in the field. Working with Barry and witnessing his passion for environmental and proper waste management practices was a pleasure. Thank you to Dr. Douglas Woolford for his statistical knowledge and recommendations. Thank you to Becky Sarazen at Surface Science Western for training me in conducting FTIR analysis on my samples.

Thank you to my partner, and best friend, Sinisa, your daily encouragement, love, and support throughout my thesis have been fundamental to my progress and success. A heartfelt thank you to my mom and brother, who have always been my pillars of strength. You both have instilled a drive in me to always pursue my passions, tackle challenging tasks and to keep going, no matter what. To my friends, I am deeply grateful for each and every one of you. Your cheers and constant support have always lifted me up and you all have been a vital part of this journey.

Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1

1 Introduction

1.1 Plastics in the Environment

The global increase in plastic debris is an urgent environmental concern (UNEP, 2023) Plastic pollution has been found in both terrestrial and aquatic environments, and its presence has been widely associated with a broad range of detrimental effects. These effects range from micro-level disruptions in cellular functions of aquatic organisms (Issac & Kandasubramanian, 2021), to macro-level ecosystem interactions and instability (Kumar et al., 2021). The ubiquity of plastic pollution serves as a marker of modern human consumption and disposal behaviors, a characteristic signature of the period informally referred to as the “Anthropocene” (Corcoran et al., 2018). The Anthropocene is a proposed epoch defined by humanity’s significant and irreversible impact on Earth’s ecosystems (Head et al., 2023). In addition, the mid-20th century experienced a period of population growth, social changes, and technological advancements known as the ‘Great Acceleration’. This is a period during which human-driven development has contributed to unprecedented production and consumption (Shoshitaishvili, 2020).

An estimated 390.7 million tonnes of plastics were produced in 2021 (Plastics Europe, 2022). This vast production of plastic results in alarmingly high rates of plastic pollution globally (Jambeck et al., 2015; Geyer et al., 2017). Under the most optimistic scenario, it is estimated that 710 million tonnes of plastic will enter the environment between 2016 and 2040 (Lau et al., 2020). Although various sources contribute to plastic pollution in aquatic environments, 80% of anthropogenic litter has been found to originate from land-based sources (da Costa et al., 2016; (Coyle et al., 2020a). The most prevalent types of land-based sources include, but are not limited to, littered waste (van Emmerik et al., 2023), ineffective waste management systems (Jambeck et al., 2015), stormwater runoff from urban areas (Lebreton et al., 2017; Grbić et al., 2020), industry spillage causing the release of plastic debris (Corcoran et al., 2015), atmospheric deposition (Smyth et al., 2021), and agricultural practices (Huang et al., 2020).

Urban areas are major contributors of plastic pollution. Impervious surfaces allow plastic litter from sidewalks, streets, and open areas to be transported by runoff into stormwater drains and ponds (Shruti et al., 2021; Baker et al., 2022). Stormwater sewer systems do not normally have filtration mechanisms to capture free-flowing debris. Stormwater can contain plastic debris of various sizes that enter storm drains and are ultimately discharged into nearby natural catchments (Browne et al., 2010; Leslie et al., 2017). A number of litter removal devices have been engineered to trap trash in stormwater basins, such as bioretention cells, trash wheels, and catch basin inserts (Lau et al., 2001; Ambrose & Winfrey, 2015). These innovative capture devices typically trap macroplastics (MaPs; >5 mm) but allow for the transfer of microplastics (MPs; <5 mm) into natural watercourses.

1.2 Objectives and Hypotheses

This thesis provides insight into a multifaceted environmental problem related to the transfer of MaPs and MPs from terrestrial to aquatic settings. The overall aim was to unravel the number of debris items, types, and sources of waste plastic deposited in London, Ontario stormwater drains prior to entering nearby waterways. The debris was captured in LittaTrap^{TM} devices with 1 mm and 5 mm mesh liners provided by Enviropod International (Enviropod, n.d.)

The main objectives of this study were to:

(1) Determine whether seasonality and human activity affect plastic debris abundance,

2) Compare the efficiency of the standard 5 mm mesh LittaTrap^{TM} insert to the 1 mm nurdle liner in trapping large microplastic (1-5 mm) particles, and

(3) Evaluate control strategy effectiveness at the post-production but pre-deposition stage of the plastic life cycle.

At the outset of the project, the following hypotheses were made: i) There will be a positive correlation between number of plastic items and precipitation amount because runoff increases during wet periods; ii) There will be a correlation (whether positive or negative) between number of items and average wind speed. The stronger winds will either blow more debris into stormwater drains or blow debris past them; iii) The amount of plastic will vary between sample sites depending on proximity to high-use pedestrian areas; and iv) The 1 mm mesh will capture a greater number of microplastic particles than the 5 mm mesh because MPs are defined as particles <5 mm in their longest diameter.

1.3 Plastic Production and Use

The first manufactured semi-synthetic plastic, developed in 1855, was composed of cellulose nitrate and camphor, and was called Parkesine after its inventor, Alexander Parkes (Parkes, 1866). In 1907, Leo Hendrik Baekeland created the world's first synthetic plastic created from a mixture of phenol and formaldehyde, known as Bakelite (Baekeland, 1909). The invention of a fully synthetic polymer proved to be a global revolutionary turning point due to its versatility, durability, low cost, and corrosion-resistant properties (Thompson et al., 2009). Throughout the 20th century, innovation in polymer science grew. The 1920s and 1930s brought forth the synthesis of polystyrene (PS), polyvinyl chloride (PVC), and acrylic, used for common everyday items to aircraft design. In 1940, plastic production rapidly increased to accommodate for the need of materials during World War II. Nylon, for example, was developed as a replacement for silk in parachutes (Flory et al., 2015). Although the creation of Bakelite occurred in the early 20th century, large-scale production and commercial use of plastic did not take place until the 1950s. In 1950, the plastic industry produced approximately 2 million tonnes of plastic compared to 460 million tonnes in 2019, equating to a 230-fold increase globally (OECD, 2022). The abundance of plastic waste in the environment directly correlates with the demand for specific products. Although there are many different types of plastics, the most produced polymers globally include polyethylene (PE), polypropylene (PP), PS, PVC, polyethylene terephthalate (PET), and polyurethane (PU) (Plastics Europe, 2022).

1.4 Properties of Polymers

Plastics are a group of materials that are considered synthetic polymers. Polymers are macromolecules that are formed by the chemical bonding of monomers through the process of polymerization (Gad, 2014). These polymers are composed of long chains with a high molecular weight, a characteristic that is common to all plastics (Sperling, 2006). Different polymerization methods are used to create polymers for which a particular property is sought. For example, ethylene (C_2H_4), derived from cracking of crude oil, is combined with a catalyst to break the C_2H_4 bond and connect carbon atoms into a chain to form polyethylene (PE). This procedure, known as addition polymerization, can be used to manufacture other chain growth polymers, such as PP, PS, and PVC. In contrast, plastics like nylons, PET, polycarbonate (PC), and PU are step growth polymers. These are formed via condensation polymerization, a process in which water is removed to facilitate the combination of two or more monomers (Sperling, 2006).

The polymerization process influences the physical properties of the polymer. The molecular weight distribution and organization of polymer chains establish the physical properties of plastic such as the firmness, flexibility, and elasticity (Verschoor, 2015). Plastics are divided into three main categories: thermoplastics, thermosets, and elastomers (Cardarelli, 2018) Thermoplastics are polymers that can be re-melted and re-formed when heated, which enables them to be highly versatile and recyclable. Thermoplastics are suitable for applications ranging from packaging to automotive parts (Andrady & Neal, 2009; Chanda & Roy, 2006). Common thermoplastics include PE, PP, PS, PVC, PET, and thermoplastic polyurethane (TPU) (Plastics Europe, 2019). Unlike thermoplastics, thermosets form irreversible bonds during the curing process and will scorch rather than melt upon heating. Once set, thermosets cannot be remelted or remolded, making them non-recyclable. This makes thermosets useful in applications in which high rigidity and thermal stability is needed, such as electrical insulation (Hale, 2002). Examples of thermosets include PU, epoxy and silicone resin, and vulcanized rubber (Shrivastava, 2018). Elastomeric polymers, when developed with reinforcing agents, such as fillers and pigments, can be stretched and then returned back to their initial form (Peters, 2015). Examples of elastomers include butadiene rubber, styrene-butadiene, isoprene rubber, and silicones (Kühne et al., 2021). Table 1-1 details some of the most common types of polymers, their densities, and applications.

1.5 Plastic Additives

During the production of plastics, additives are often used to strengthen and/or protect the polymer matrix (Thompson et al., 2009). There are many different additives that serve a unique purpose. Most common polymer additives include plasticizers, stabilizers, lubricants, flame retardants, fillers, and colorants (Groh et al., 2019). Plasticizers are commonly used to provide increased flexibility by reducing the intermolecular forces between polymer chains (Marturano et al., 2017). Typical plasticizers are phthalates, adipates and polychlorinated hydrocarbons (Godwin, 2017). Stabilizers are chemical additives used to slow the rate of degradation. Examples of stabilizers are antioxidants, UV light, and heat (Singh & Sharma, 2008). Lubricants can impact the polymer strength and improve the distribution of other additives in the matrix. Flame retardants are used to both physically and chemically decelerate fire propagation (Schartel et al., 2017). Fillers are used to change the properties of polymers and are either inert or active. Inert fillers are bulking agents that improve mechanical properties. Common inert fillers include talc, glass beads, and calcium carbonate. Active fillers allow for the formation of bonds between polymer chains, which increases the material strength, heat resistance, and malleability (Vikhareva et al., 2021); Xanthos, 2010; Sperling, 2006). Plastic colorants include dyes and pigments. Dyes provide a transparent hue and have less stability in high levels of sunlight due to their increased solubility (Pfaff, 2022). In contrast, pigments provide a consistent opaque coloration throughout a polymer and have higher resistivity to UV degradation because they are insoluble in a medium (Muller, 2011; Pfaff, 2022). This makes pigments less prone to leaching, migration and diffusion.

Table 1-1. The most prevalent polymers and common applications (SpecialChem, 2023; British Plastics Federation, n.d.; ECCC & HC, 2020; Callister & Rethwisch, 2018).

Polymer	Abbreviation	Min Density (g cm^{-3})	Max Density (g cm^{-3})	Applications and Usage
Polypropylene	PP	0.9	0.91	food packaging/wrappers, automotive parts, microwave containers
Polyethylene	PE	0.91	0.97	semi-rigid and flexible packaging, housewares, electrical insulation
Low density polyethylene	LDPE	0.91	0.93	packaging film, waste bags, toys
Linear low-density polyethylene	LLDPE	0.91	0.94	milk cartons, produce bags, take-out cups
High density polyethylene	HDPE	0.94	0.97	plastic milk bottles, caps, detergent bottles
Acrylonitrile butadiene styrene	ABS	1.00	1.05	automotives, keyboards, household appliances, toys
Polystyrene	PS	1.01	1.04	food packaging, meat trays, insulation, packing peanuts
Polyamide (nylon)	PA	1.02	1.05	textiles, fishing lines/nets, racquets, umbrellas
Polyacrylonitrile	PAN	1.09	1.20	knitwear, blankets, carbon fibre production
Liquid Silicone Rubber	LSR	1.10	1.50	silicone sealants, food storage products, medical tubing
Polyvinyl chloride	PVC	1.16	1.58	window frames, pipes, electronic insulation
Polymethyl methacrylate	PMMA	1.17	1.2	glasses, Plexiglass, lenses, LCD screens
Cellulose acetate	CA	1.22	1.34	cigarette butts, camera film, ribbon, eye glass frames
Polylactic acid	PLA	1.23	1.26	automotive parts, textiles, food packaging
"Polyester"	PET	1.24	2.30	clothing, textiles, insulation in home goods
Polyethylene terephthalate	PET	1.37	1.45	drink bottles, cleaning supply products

1.6 Plastic Debris Classification

Plastic debris items are commonly classified into three size categories: nano, micro, and macro. Although size classifications are not standardized across studies (Blair et al., 2017), this thesis adopts macroplastics (MaPs) as whole items or fragments >5 mm in size. Macroplastics are visually detectable and over extended environmental exposure, break down into smaller fragments known as microplastics (MPs) (Andrady, 2011). Carpenter & Smith (1972) were the first authors to publish a scientific paper concerning marine MPs after estimating the average concentrations of plastic particles in the western Sargasso Sea. The term microplastic, however, was first introduced in 2004 by marine biologist Richard Thompson to describe the long-term accumulation of microscopic fragments and their potential impacts on marine organisms (Thompson et al., 2004). Arthur et al. (2009) later suggested a maximum size limit of 5 mm to define MPs.

Microplastics are divided into primary and secondary categories based on their origin (Cole et al., 2011). Primary MPs are produced to be < 5 mm, and include items such as microbeads, microfibres, and plastic pellets. Secondary MPs are produced through breakdown of larger plastic products, and examples include fragments and films. Once in the environment, MPs can break down into even smaller particles through biological, chemical, and mechanical degradation processes (Zhang et al., 2021; Corcoran, 2022). The resultant nanoplastics pose an increasing threat to the health of both aquatic and land-based organisms of various sizes.

1.6.1 Morphology of Plastic Particles

The common microplastic morphologies found in both aquatic and terrestrial environments include fragments, fibres, beads, foams, and films (Figure 1.1). Synthetic fibres are the predominant type of microplastic, found in marine, fresh water, and air (De Falco et al., 2020). Large amounts of MP fibres are discharged from the washing of synthetic textiles (Boucher & Friot, 2018; (Napper & Thompson, 2016). Fibres detach from textiles and enter wastewater treatment systems (Grbić et al., 2020). In addition, wet wipes and cigarette filters release significant microfibres (Ó Briain et al., 2020; Belzagui et al., 2021). Mishra et al., (2019) estimate that 2 million tonnes of microfibres are released into the ocean each year, and that there are currently 1.5 million trillion microfibres in the ocean.

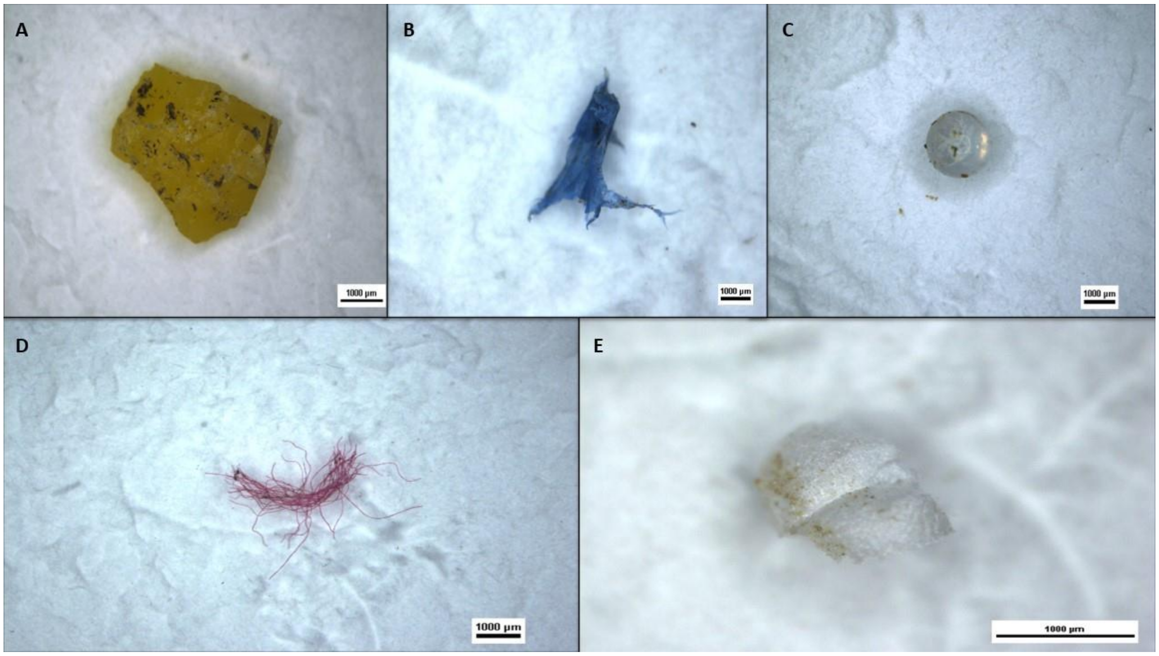

Figure 1-1. Different morphological types of microplastics. (A) Fragment, (B) Film, (C) Bead, (D) Fibres, and (E) Foam.

Fragments are most commonly found in marine environments (Cohen et al., 2019; (Kosore et al., 2022). Fragmented MPs are derived from larger macroplastic debris and typically exhibit irregular shapes commonly composed of PE, PP, PET, and PS (Erni-Cassola et al., 2019). Recently, it was suggested that irregularly shaped MPs adsorb more pollutants than rounded or spherical morphologies because of their higher surface area to volume ratio (Frydkjær et al., 2017; Zimmermann et al., 2020). This results in greater accumulation of polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), hexachlorocyclohexanes (HCHs), dichlorodiphenyltrichloroethane isomers (DDTs), and pesticides (Patel et al., 2020; Li et al., 2022; Prajapati et al., 2022).

Microbeads are manufactured for specific uses, typically being found in personal care and cosmetic products (e.g., shampoos, toothpaste, lotions, lipstick), and abrasives and exfoliants (Bhattacharya, 2016; Hunt et al., 2020). Microbeads are one of the only microplastic types with increasing restrictions around the world (Stoll et al., 2020). The ‘rinse-off’ nature of personal care products and small size of microbeads contribute to the leading form of microplastic escape capacity from wastewater treatment plants (WWTPs) (Hidayaturrahman & Lee, 2019). Approximately 90% of all microbeads are composed of PE, but PP, PET, PMMA, and nylon are also used for microbead production (Gouin et al., 2015).

Foam MPs originate from larger foam materials commonly used in single-use food containers, packaging materials, insulation, and construction materials (Ramli Sulong et al., 2019; Turner, 2020). The low density, thermally insulating, and shock-absorbing characteristics of plastic foams such as expanded polystryrene (EPS), extruded polystyrene (XPS), and PU spray foam make these polymers highly desirable in commercial applications (de Souza et al., 2023). Among these foams, EPS and XPS are the most predominant forms of marine litter (Chen et al., 2018; (Chitaka & von Blottnitz, 2019).

Films are thin, malleable, flat sheets of plastic derived from the degradation of larger plastic items, such as single-use shopping bags, food packaging, industrial liners, and agricultural films (Rochman et al., 2019; Thammatorn & Palić, 2022; (W. Yang et al., 2022). Films are typically composed of HDPE, LDPE, LLDPE, and PVC (O’Rourke et al., 2022).

1.7 Ecological and Environmental Impacts of Plastic Debris

Plastic pollution directly and indirectly harms organisms and ecosystems. This thesis concerns plastic debris in terrestrial systems that lead directly into freshwater environments.

1.7.1 Terrestrial

The majority of plastics are produced, used, and discarded on land, contributing to an accumulation of waste in terrestrial systems (Hurley et al., 2020). Land areas with high population density and anthropogenic activity, such as urban centers, along with locations near waste processing sites, tend to be the largest repositories for the accumulation of MaPs (Barnes et al., 2009). Plastic waste on land has contributed to the accumulation of both MaPs and MPs in rivers (Lahens et al., 2018; Corcoran et al., 2020; Pan et al., 2023) and lakes (Ballent et al., 2016; Li et al., 2018; Yang et al., 2022). Although various sources contribute to microplastic pollution in aquatic environments, 80% of anthropogenic litter originates from land-based sources (da Costa et al., 2016; Coyle et al., 2020). The most common type of land-based source is stormwater runoff containing littered waste. Plastics may also be spilled within factories then drain into local water bodies. Agricultural activities contribute plastic waste to the environment through cultivation, and the use of plastic mulch films and synthetic fertilizers coated in different polymers (Tian et al., 2022, and Zhang et al., 2020). During rain events, these MPs may run off into aquatic systems.

In terrestrial environments, tire wear particles are also a large contributor to microplastic emissions globally (Schwarz et al., 2019). Estimates state that the global average emission rate of tire wear particles may be 0.81 kg/year (Kole et al., 2017) Recent studies have also revealed that MPs found in terrestrial settings may have been deposited through air (O'Brien et al., 2023). According to Evangeliou et al. (2020) wind erosion acts as a natural transport mechanism, distributing MPs across different environments and ultimately contributing to their widespread distribution. Microfibres, derived from textiles such as fabrics, clothing, and carpets, are the dominant types of MPs in air (Finnegan et al., 2022). Other sources of MPs found in the atmosphere come from industrial activities. Recycling plants, factories, and manufacturing plants, where plastic incineration and grinding processes are carried out, contribute to airborne MP pollution (Dris et al., 2016).

1.7.2 Freshwater

The study of plastic pollution within freshwater environments is generally considered to be less extensive than that in marine environments. However, recent recognition of rivers and lakes as major conduits for plastic debris entering the marine environment has shifted attention towards plastic pollution in freshwater environments (Horton & Dixon, 2018).

Meijer et al. (2021) predict that 1656 rivers are accountable for 80% of plastic emissions into the marine environment, with small urban rivers contributing the most pollution.

Freshwater ecosystems may also experience the direct impacts of plastic pollution. According to Blettler & Mitchell (2021) freshwater fauna interact with MaPs and MPs in several distinct ways, similar to marine counterparts. These interactions include: (1) ingestion; possibly leading to internal injuries, (2) entanglement; animals are trapped in plastic, (3) nesting; the use of plastic to build nesting sites, (4) biota transfer; using plastic for transportation across landscapes, and (5) shelter; providing a refuge for various species. Biota in aquatic environments are susceptible to the ingestion of MPs and have been found in various ecosystems worldwide (Rochman et al., 2015; Chae & An, 2017; Besseling et al., 2019). Out of all species, birds are the most reported in plastic-fauna encounters (Wang et al., 2021). It is expected that by 2050, all seabird species will be ingesting plastics (Wilcox et al., 2015). A study by Brookson et al. (2019) revealed that of 30 species of cormorants (*Phalacrocorax auratus*) native to the Laurentian Great Lakes, >86% contained MPs and other anthropogenic materials, with fibres being the most abundant. The interaction and ingestion of MPs have been reported from nearly every trophic level, including in algae, phytoplankton, and zooplankton (Wu et al., 2019; Hitchcock, 2022; Yıldız et al., 2022), invertebrates (snails, mussels, and insects) (Pan et al., 2021), fish and amphibians (Wardlaw et al., 2022), birds and mammals (Reynolds & Ryan, 2018; Smiroldo et al., 2019), and plants (van Weert et al., 2019). In their review, Azevedo-Santos et al. (2021) found that 206 freshwater species were found to have ingested plastic, ranging from small invertebrates to mammals.

Plastics can also adsorb pollutants that are then ingested by aquatic organisms, thereby creating the potential to disrupt the food chain (Auta et al., 2017; (Saeedi, 2023). Plastics have been shown to leach as well as adsorb harmful substances such as heavy metals (Zon et al., 2018), endocrine-disrupting chemicals ((Grgić et al., 2023) and organic pollutants (Liu et al., 2019). The resultant effects include bioaccumulation, reproductive issues, and toxicity. (Mariani et al., 2023) reported that aquatic moth larvae *Cataclysta Lemnata,* fed with microplastic-contaminated plants showed induced mortality rates of 90% and failure to reach the adult phase after 21 days, whilst 50% of the control group managed to pupate as moths. In a 60-day study by Herrera et al. (2022), European seabass (*Dicentrarchus labrax)* were fed two diets containing 10% virgin plastic or environmental MPs. The fish ingesting environmental MPs revealed bioaccumulation of polybrominated diphenylethers (PBDEs) (used as flame retardants in polymers), polychlorinated biphenyls (PCBs), and Dichlorodiphenyldichloroethylene (DDE) in their livers. Several studies have shown that MPs with heavy metal contaminants can also cause toxic effects (Naqash et al., 2020; (Q. Chen et al., 2023)). A study done by Banaee et al. (2019)revealed that when MPs and cadmium chloride (Cd) are combined, they intensify the effects of biochemical and immunological stressors on common carp (*Cyprinus carpio*).

1.7.3 Human Health Implications

The presence of MPs in the human body is a relatively new area of research that is quickly evolving but remains understudied (Kutralam-Muniasamy et al., 2023). There are three main methods of microplastic exposure to humans: (1) ingestion, (2) inhalation, and (3) dermal contact (Prata et al., 2020). According to a study published by Cox et al. (2019), humans are exposed to 74,000 to 121,000 MPs annually. Ingestion is the main way in which humans are exposed to MPs (Kumar et al., 2022). Numerous studies have shown that MPs and nanoplastics are in commonly consumed foods and beverages, such as tap and bottled water (Gambino et al., 2022), table salt (Gündoğdu, 2018), commercial fish and shellfish (Rochman et al., 2015); Li et al., 2018; Fang et al., 2019), milk (Basaran et al., 2023), sugar (Afrin et al., 2022), tea bags (Hernandez et al., 2019, Thiele et al., 2021), and fresh produce (Oliveri Conti et al., 2020). Experimental findings from both cellular and animal models indicate that MPs may impact multiple physiological systems including gastrointestinal, pulmonary, hormonal, reproductive, and immunological. Various studies have investigated a number of biological disruptions such as oxidative stress, wherein plastic additives such as phthalates, and bisphenol A (BPA) have the ability to damage cellular components (Liu et al., Schirinzi et al., 2017). Cytotoxicity has been determined in human colon adenocarcinoma Caco-2 cells by the introduction of polystyrene MPs (Wu et al., 2019). Neurotoxicity has also been observed (Prüst et al., 2020). An in vitro study revealed that murine neuronal cell types, when exposed to polystyrene nanoparticles, can affect the mitochondria and cause increased lactate dehydrogenase (LDH) leakage, a marker for cell damage (Murali et al., 2015). In addition, immune system disruption through inhalation can result when MPs interact with alveolar epithelial A549 cells, by interfering with the cell cycle, and encouraging apoptosis, causing induced inflammation (Xu et al., 2019).

1.8 Summary

The ubiquity of plastic waste in the environment and the harm it poses to organisms necessitates urgent research, planning, and solutions that will help stem the flow of plastic debris into terrestrial and aquatic ecosystems. One way to address this danger is to examine, quantify, and assess the types of plastics that are currently accumulating in the environment. This helps in identifying the sources, pathways, and main factors controlling the accumulation and deposition of MaPs and MPs. The remainder of this thesis will provide novel results and interpretations that answer the question, “How many and which types of plastic debris items are transferred from urban streets into freshwater aquatic settings through stormwater drains?”

2 Regional Setting and Methodology

2.1 Regional Setting

The city of London in Ontario, Canada, is an area with a population of approximately 423,369 (Statcan, 2021). Ranked by population, London is the sixth-largest city in Ontario in addition to being Canada's 10th largest city. London has a land area of 420 km^2 with a population density of 1,066/km^2 (Statcan, 2021).

There are many waste management services in London, such as recycling, and yard waste and garbage collection. The city is also introducing a Green Bin program in January 2024 for food waste collection (City of London, 2023). Curbside waste collection contributes 61,000 tonnes of residential garbage annually, whereas multi-residential households contribute 23,000 tonnes. Approximately 7% of waste from curbside garbage pick-up is recyclable. In 2017, The City of London proposed a Resource Recovery Strategy to maximize waste diversion from the current rate of 45% to a rate of 60% (City of London, 2020). Accepted plastics for recycling include plastic containers, plastic bottles and tubs with RIC #1 through #7. Not all plastic items are recyclable in London, such as Stryofoam (expanded polystyrene), plastic bags, plastic straws, plastic cutlery and plastic wrap.

The Thames River flows through rural, suburban, and urban parts of London (Figure 2.1). The river is located in southwestern Ontario, Canada, and is known as the Deshkaan-ziibi / Eshkani-ziibi ("Antler River") by the Anishnaabe peoples (Thames River Clear Water Revival, 2019). The river flows 273 km with a total drainage basin of 5,825 km^2 and a maximum width of 56 km (Stewart & Desloges, 2014). The Upper Thames River is composed of three sections: i) the south branch, which begins near Tavistock, ii) the middle branch, which originates near Hickson and flows into the south branch near Putnam, and iii) the north branch, which begins near Mitchell (Figure 2.1). The north and south branches converge in downtown London and become the Lower Thames River, which flows into Lake St. Clair.

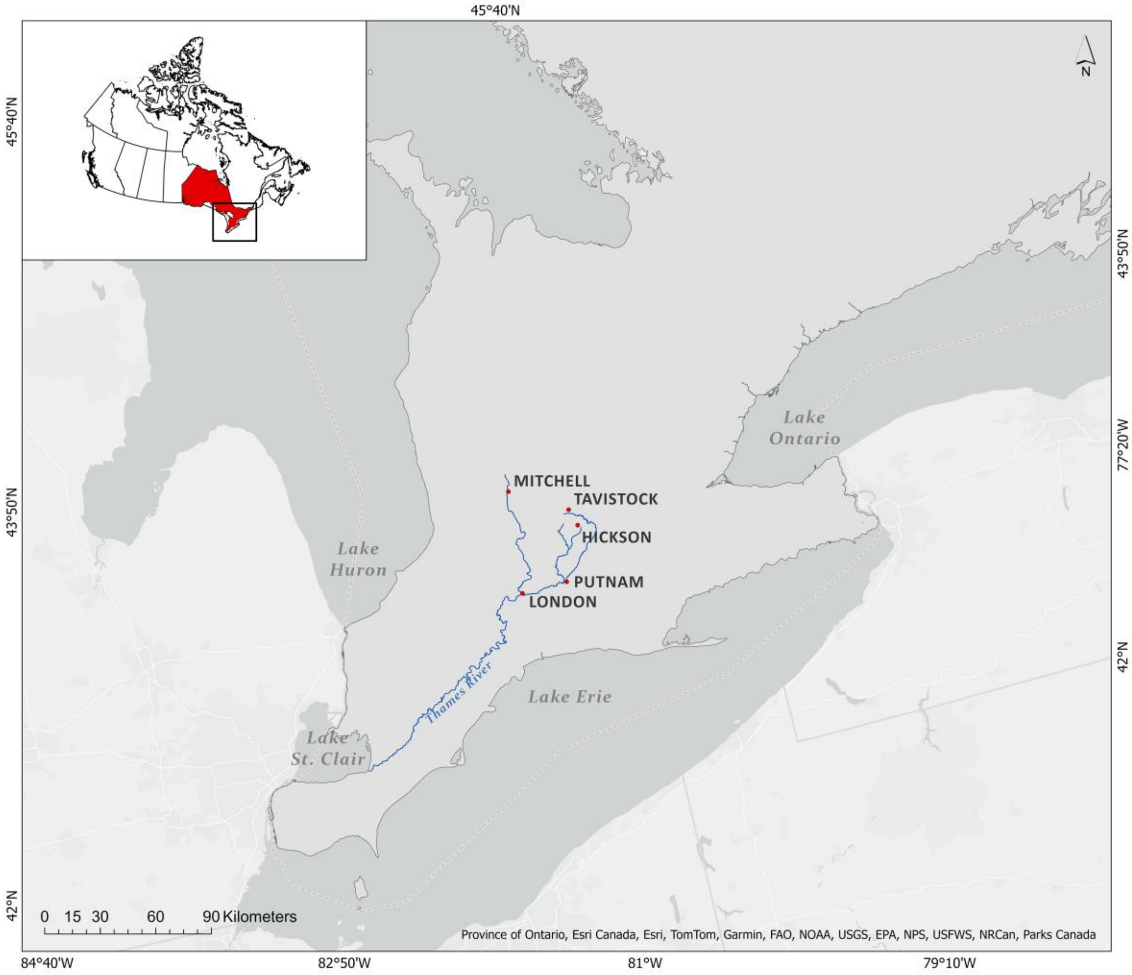

Figure 2-1. Location of London, Ontario at the confluence of the upper and lower portions of the Thames River. The towns of Mitchell along the north branch, Tavistock and Putnam along the south branch, and Hickson along the middle branch of the Upper Thames are indicated. The Thames River is located within the Great Lakes Watershed. Map produced in ArcGIS Pro.

The Thames River is impacted by London's growing population, thereby increasing the potential risks of pollution, and specifically plastic debris. To understand the relationship between land-based sources of plastics and their input into freshwater systems, the urban areas surrounding the Thames River present a critical study site. This study area allows for the consideration of how anthropogenic activities contribute to the accumulation of MaPs and MPs in natural ecosystems. Examining stormwater drain debris in London allows for their capture, sorting, quantification, and categorization. These processes aid in identifying the sources of plastic waste and its pathways into natural, freshwater systems. The present study therefore provides vital insights for environmental management and pollution mitigation strategies.

2.2 Methodology

A total of 30 samples were collected from urban stormwater drains in London, Ontario. All samples were processed using a density separation method. Macroplastic and large microplastic particles were characterized visually and microscopically. Fourier transform infrared spectroscopy (FTIR) was used to determine the polymer composition of microplastic particles.

2.2.1 Sample Collection

Samples were collected seasonally from six different stormwater drains (Figure 2.2). The locations of the drains are classified as high priority zones by the City of London and include Dufferin, Inner Queens, Outer Queens, Bathurst, Ivey Park, and Carfrae sites (Figure 2.3). The stormwater drains are all distributed within the downtown core of the city. At each of these sampling locations, an Enviropod LittaTrap^{TM} with a 5 mm mesh size was previously installed by the City of London. The patented trap is designed to act as a catch basin to prevent anthropogenic and other debris from entering the storm drain system (Figure 2.3). The debris in the 5 mm mesh traps were collected from each location in October 2021 as single reference standards to be compared with the results later determined from the 1 mm mesh liners. Each LittaTrap^{TM} was then retrofitted with an Enviropod Nurdle Liner^{TM}, which is composed of a finer mesh designed to catch debris > 1 mm (Figure 2.4). The 1 mm mesh was installed to determine the effectiveness of larger microplastic capture (1-5 mm in size). Each 1 mm liner was installed for a 22-day period, once per season.

During autumn sampling, the fine mesh was installed on November 25, 2021 and removed on December 16, 2021. During the winter period, accumulation occurred between March 10, 2022, and March 31, 2022. The spring sampling period was from May 26, 2022 to June 16, 2022, and the summer sampling period ran from August 25 to

September 14, 2022. Debris that accumulated during each sampling period was removed and emptied into 22L stainless steel cans with locking lids to avoid airborne plastic contamination of the sample.

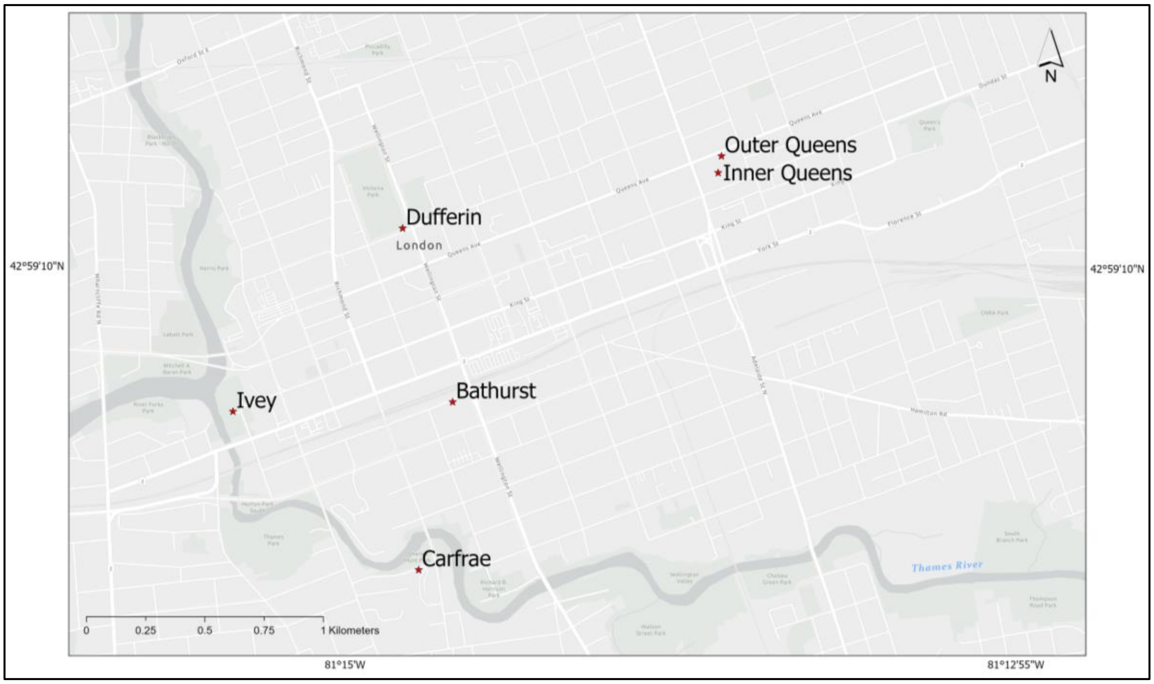

Figure 2-2. Map displaying the locations of the sampling sites and the Thames River in London, Ontario. Map produced in ArcGIS Pro.

2.2.2 Sample Processing

Each sample contained organic and plastic debris, and some contained sediment. The samples were visually examined, and any anthropogenic debris >5 mm (MaPs) was removed. The MaPs were rinsed with reverse osmosis (RO) water, placed in aluminum pie plates, covered with aluminum foil and placed in a drying oven set to 60°C for 24 hours. The remaining debris in each can was processed using a density separation method similar to the International Trash Trap Network’s detailed waste characterization protocol (Ocean Conservatory, n.d.).

Figure 2-3. Photos of the six stormwater drains from which the samples were collected. A) Bathurst, B) Ivey Park, C) Dufferin, D) Carfrae, E) Outer Queens, and F) Inner Queens.

The sample contents were combined with RO water until the 22 L steel can was ¾ full. The contents were thoroughly stirred with a metal spoon and left to settle for 3 minutes to allow small particles to float to the water surface. Macroplastic debris visible at this stage was removed and added to the MaPs previously identified. A 28 cm diameter stainless steel sieve was pressed into the sample and slowly pushed down toward the bottom of the can. Each sample was then poured through a 1 mm VWR USA Standard Testing Sieve, and an overlying 5 mm VWR USA Standard Testing Sieve. The 5 mm sieve allowed for the additional capture of any entangled debris that was missed in the initial steps of processing. This process was repeated three times. Each time, the contents captured in the 1 mm sieve were rinsed into glass petri dishes, covered with aluminum foil and dried in the laboratory oven at 60°C for a minimum of 24 hours. Once all samples were cleaned and dried, each individual piece of debris was visually identified, measured, and recorded (Figure 2.5).

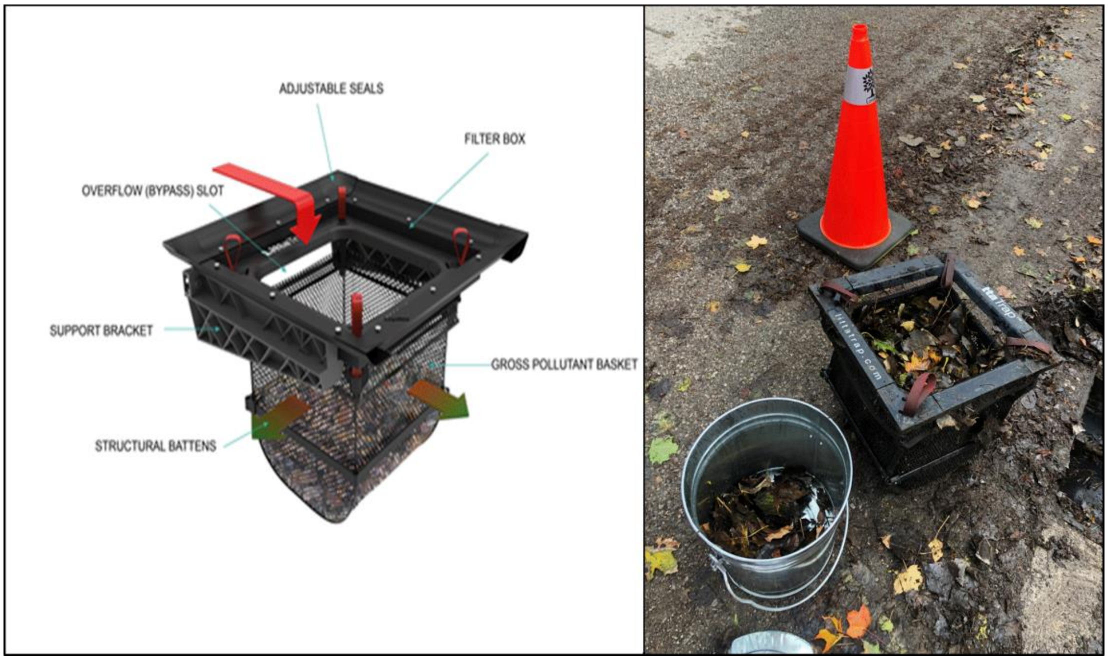

Figure 2-4. Schematic diagram of the LittaTrap^{TM} catch basin (left) and during field sampling (right).

Macroplastic items were categorized using a visual characterization method. This method involved: 1) recording of known item parts (e.g., cigarette butts, bottle caps, food wrappers), 2) using attached labels or markings for identification, and 3) conducting online searches for comparison by using Resin Identification Codes (RIC). For microplastic particles, each petri dish containing a processed sample was examined using a Nikon SMZ1500 stereomicroscope (3.75x to 258x magnification), each particle was photographed using a Nikon DXM1200 digital camera and was measured in NIS elements D 4.30. Each particle was removed with a stainless-steel dental pick or tweezers, and was categorized according to colour, size, and type (pellet, fragment, intact fragment, foam, fibre, film, rubber, and non-plastic). Table 2-1 displays the characterization method used to create the database for this study. Each particle was placed onto double-sided 3M adhesive tape adhered to a glass microscope slide and was circled with a black, fine-tip permanent marker. Once a slide was filled with particles, it was stored within an air-tight box.

Figure 2-5. Organization of macroplastic and other debris from the autumn Bathurst sample prior to visual characterization.

2.2.3 FTIR

Fourier Transform Infrared Spectroscopy (FTIR) is a compositional analysis method used on an unknown material to determine composition. This identification technique is common in polymer science. The surface of a particle is exposed to infrared light and the radiation absorbed or reflected by the molecules within the particle creates energy with a unique spectrum (Giechaskiel & Clairotte, 2021). A total of 150 microplastic particles were selected using a random number generator to be analyzed by FTIR at Surface Science Western, London, Canada. Particles were transferred to a diamond compression cell, condensed, and analyzed using a Bruker Tensor II spectrometer in transmission mode, using a Hyperion 2000 microscope. Larg MP particles were analysed using a micro-attenuated total reflectance (mATR) attachment equipped with a germanium crystal. Spectra were collected from wavenumbers 4000 to 600 cm^{-1} with a resolution of

4 cm^{-1}. The results were baseline corrected, and corrected for possible contamination from water vapour, carbon dioxide, and the adhesive tape.

Table 2-1. Categories and identification procedure used to describe each particle and item found in the samples.

Category	Identification Variable
Location	Bathurst Carfrae Dufferin Inner Queens Ivey Park Outer Queens
Size	Microplastic: Size (µm) Macroplastic: Size (cm) Size Fraction: <5 mm >5 mm
Particle Morphology	Intact Fragment Fragment Pellet Fibre Foam Film Textile Rubber Other
Quantity	Dependent
Colour	Specific to particle/item
Description	Physical description RIC identification codes
Material	FTIR results recorded for selected particles and items Identifiable items were researched to determine polymer composition
Uses/Application	Items and particles were cross-referenced with web searches to determine their common applications: Arts/Crafts Clothing/Textiles Construction Food/Beverage Packaging Industrial Coatings Narcotics Medical Packaging Unknown

2.2.4 Quality Assurance and Quality Control

Quality assurance and control measures were taken to minimize the amount of airborne microplastic contamination in the samples. A total of 16 procedural lab blanks and 8 field blanks were collected to determine the levels of contamination during working hours in the laboratory, and at the time of sample collection, respectively. During removal of the LittaTraps^{TM} in the field, glass mason jars were set next to the storm drains in order to account for atmospheric fallout. The jars were covered with aluminum foil and brought back to the lab where they were rinsed with RO water and drained into glass petri dishes. The laboratory blanks were acquired by placing empty glass petri dishes on counters during processing and microscopic examination of individual samples. In the laboratory, all processing tools were thoroughly rinsed with RO water, dried with compressed air, and covered with aluminum foil when not in use. All surfaces were wiped with damp cotton towels before and after use, including chairs, work benches, sinks, and metal microscope enclosures. Clean-air measures were enforced using filters and HEPA air purifiers. Individuals entering the lab at any time were required to wear white cotton lab coats and designated lab footwear.

3 Results

Anthropogenic debris found in each trap insert were separated into macroplastic (items >5 mm) and microplastic (particles from 1-5 mm) categories. All items and particles were weighed and characterized based on size, color, and type (Appendix 1; Table 3-1).

3.1 Macroplastics

3.1.1 Macroplastic Quantification

A total of 1450 plastic debris items were quantified from all samples. The greatest number of MaPs were found in samples from the Bathurst site, with a total of 568 items (Figure 3.1). The Dufferin samples contained the second-highest count of MaPs, with 274 items. The Inner Queens samples contained 267 items, whereas the Outer Queens samples had 186. The Carfrae and Ivey Park samples contained lower counts, with 84 and 71 items, respectively.

The greatest number of MaPs at the Bathurst site were collected from the spring sample (158 items), followed by autumn (152 items), then summer (113 items) (Figure 3.2). The lowest counts were recorded from the winter (86 items) and the standard (59 items) samples. The Carfrae winter site contained 28, followed by spring and summer, both containing 19 items, and 11 items in the autumn sample. The standard contained the lowest number of MaPs with 7 items. The Outer Queens site also contained the lowest number of MaPs in the standard (10 items) compared to the summer (59 items), spring (51 items), autumn (33 items), and winter (33 items) samples. In contrast to the Bathurst, Carfrae, and Outer Queens sites, the Inner Queens site standard contained the greatest number of MaPs (89 items) compared to the summer (62 items), spring (48 items), autumn (45 items), and winter (23 items) samples (Figure 3.2). Similarly, the Ivey Park site had the highest number of MaPs in its standard (26 items) compared to the spring (20 items), autumn (11 items), summer (9 items), and winter (5 items) samples. The Dufferin site summer sample contained the highest number of MaPs (119 items) followed by the spring (65 items), winter (37 items), standard (31 items), and autumn (22 items) samples.

3.1.2 Macroplastic Morphologies

The morphology of each macroplastic item from every sample was recorded, and these included fragments (unidentifiable source), intact fragments (identifiable source), foams, textiles (e.g., woven synthetic fabric, rope, line, thread), films (thin, flexible plastics), rubber, and visible non-plastics (Figure 3.3). Fragments and intact fragments were the most prevalent item types across all sites, with their totals ranging from 16.7% to 61.3% per site. Intact fragments accounted for 36.5% of the total macroplastic debris. This was followed by fragments (32.4%), rubber (1.6 %), foams (3.2%), films (13.4%), and non-plastics (12.1%). The least common morphology type was textiles, representing 0.9% of the overall macroplastic debris. The relative percentages of morphology types in the samples were calculated for each site. Of the six sites, the percentages of fragments and films were greatest in the Inner Queens samples (51.0%; 14.1%), of intact fragments and rubber in the Dufferin samples (61.3%, 2.0%), of foams in the Carfrae samples (15.6%), of textiles in the Ivey samples (2.4%), and of non-plastics in the Bathurst samples (15.5%) (Figure 3.3).

Table 3-1. Summary table showing the weights and counts of samples, items, and particles.

Name of Trap	Total weight of wet debris (kg)	Dry weight of MaPs (g)	Count of MaPs	Dry weight of MPs (g)	Count of MPs
Standard					
Ivey Park	1.473	2.637	26	0	6
Inner Queens	1.493	23.489	89	0	20
Outer Queens	0.107	6.328	10	0	8
Bathurst	1.264	26.340	59	0.053	29
Carfrae	7.562	1.718	7	0.038	12
Dufferin	3.394	48.515	31	0.165	26
Autumn					
Ivey Park	3.315	0.910	11	0.023	3
Inner Queens	4.455	16.370	45	1.358	195
Outer Queens	2.476	1.310	33	0.038	54
Bathurst	0.434	231.370	152	0.614	144
Carfrae	1.941	0.000	11	0.080	35
Dufferin	2.654	8.153	22	0.175	75
Winter					
Ivey Park	0.311	1.100	5	0.200	26
Inner Queens	0.465	1.200	23	0.229	72
Outer Queens	0.567	4.600	33	0.135	53
Bathurst	0.595	49.300	86	0.378	93
Carfrae	1.388	1.210	28	0.098	139
Dufferin	0.669	4.700	37	0.331	359
Spring					
Ivey Park	17.146	19.930	20	0.291	67
Inner Queens	20.114	15.780	48	0.177	83
Outer Queens	3.137	65.970	51	0.479	41
Bathurst	10.436	17.960	158	0.369	136
Carfrae	3.575	15.640	19	0.389	88
Dufferin	0.745	2.440	65	0.193	111
Summer					
Ivey Park	0.114	4.390	9	0.011	32
Inner Queens	23.766	88.350	62	0.498	213
Outer Queens	3.377	19.310	59	0.067	80
Bathurst	0.182	45.320	113	0.467	131
Carfrae	0.606	11.250	19	0.053	18
Dufferin	1.534	555.140	119	0.383	144

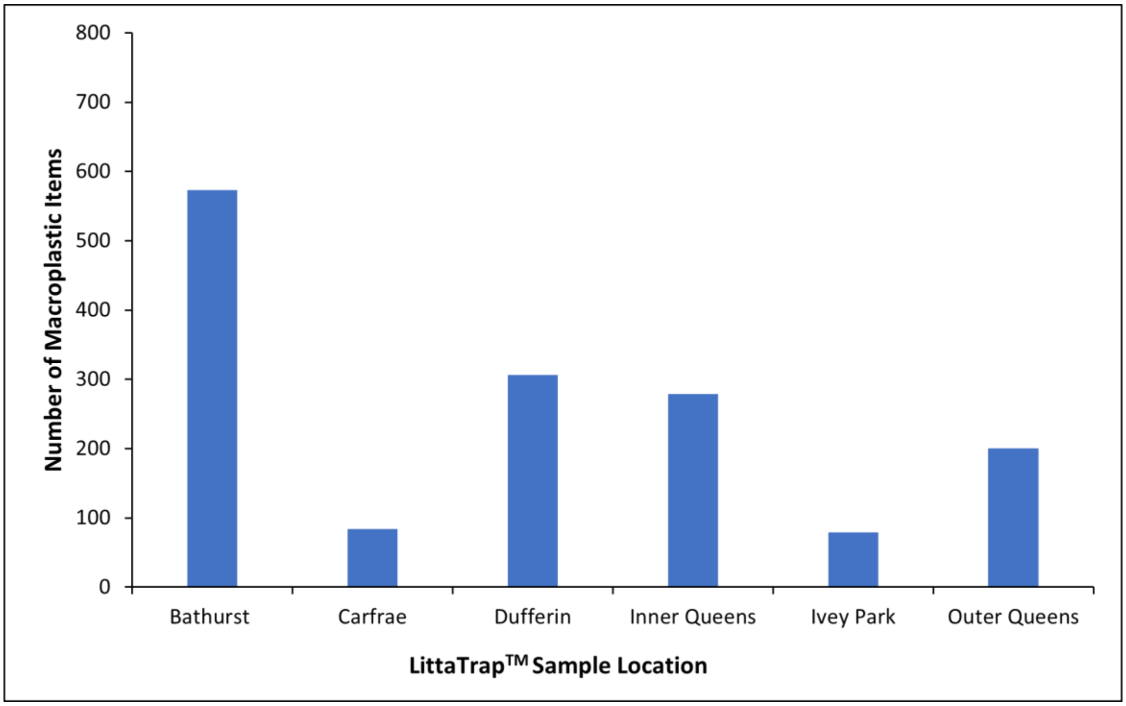

Figure 3-1. Total Count of MaPs from each site combined across all seasons.

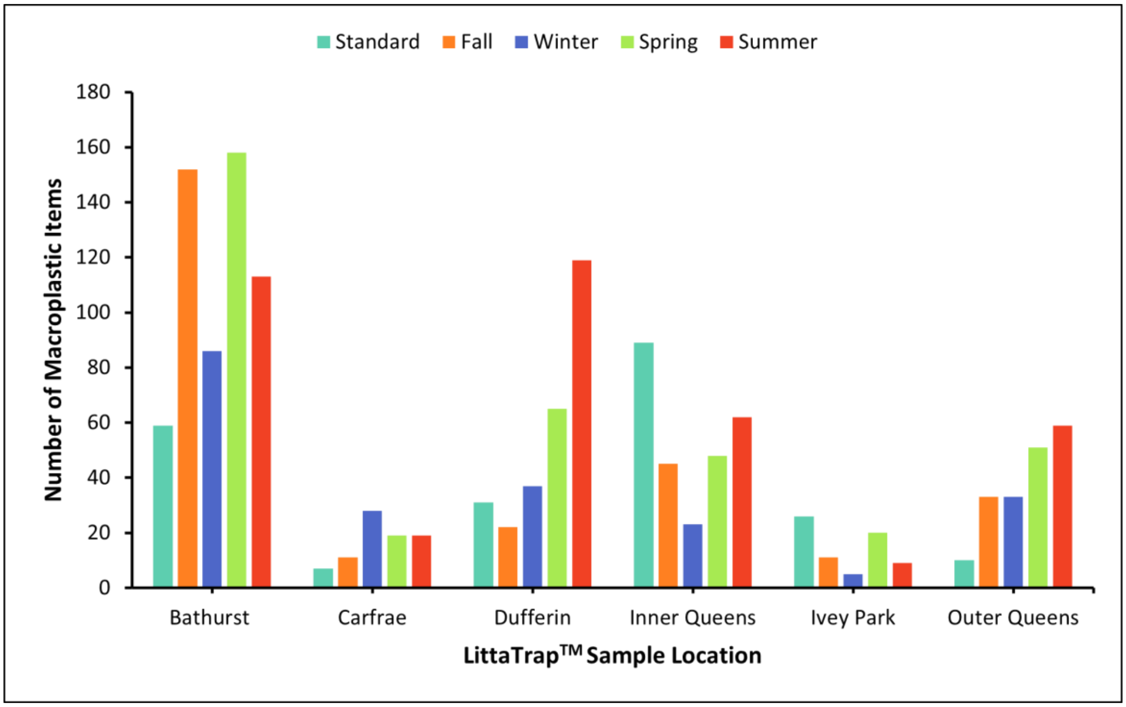

Figure 3-2. Seasonal abundance of macroplastic debris found in the 1 mm mesh compared with the standard sampling period debris from the 5 mm mesh.

3.1.3 Macroplastic Items and Polymers

Visual analysis of all debris revealed a diverse range of items (Figure 3.4). Cigarette butts were the most common macroplastic, constituting 455 (31.4%) of the total items surveyed. Fragments accounted for 313 (21.6%) of the total items. Wrappers (121, 18.3%) and expanded polystyrene (EPS) foam (5, 3.5 %) were also common. Other notable MaPs included bottle caps (35, 2.4%), films (28, 1.9%), and saline solution caps and bottles (26, 1.8%). Numerous other common items were found in limited numbers, such as vehicle light fragments (18, 1.2%), medical packaging (16, 1.1%), food packaging (15, 1.0%), syringes (12, 0.8%), plastic bags (12, 0.8%), drinking straws (8, 0.6%), and apothicom cups (5, 0.3%).

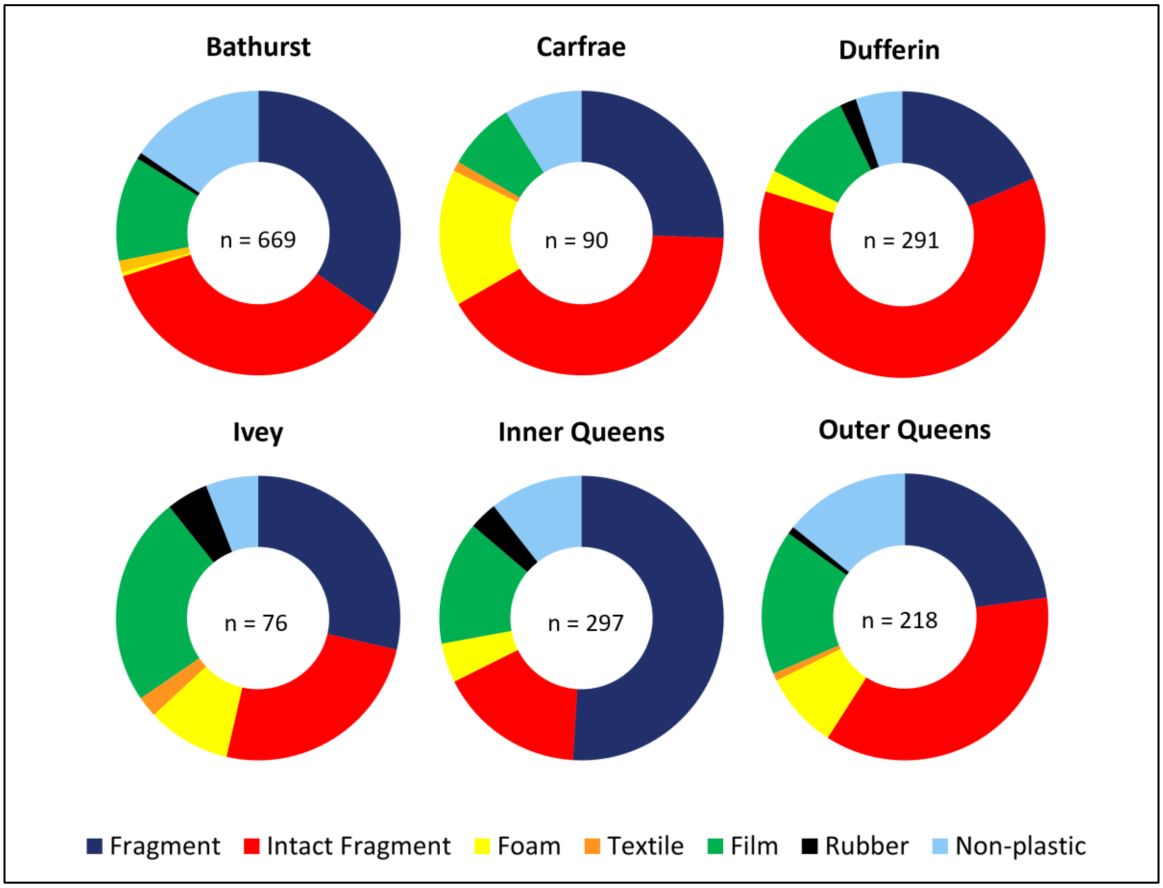

Figure 3-3. Relative percentages of macroplastic debris types in each sample across all seasons.

Using the visual polymer identification process described in section 2.2.2, 572 items (39.4%) were unidentifiable (Figure 3.5). Of the remaining 878 items, cellulose acetate (cigarette butts) was the most common polymer, making up 51.8% of the total. Polypropylene, HDPE, and EPS were also prominent, at 10.5%, 9.3%, and 5.9%, respectively. Rubber and PE comprised 2.7% and 1.8% of the total items, respectively. Low-density PE and acrylic accounted for 2.3% and 1.6% of the identified total, whereas PET represented 1.9%. Polycarbonate (PC) (2.2%), alkyds (1.7%), and polyvinyl chloride (PVC) (2.2%) were identified as the polymers for vehicle light fragments, paint, and tubing, respectively.

3.1.4 Macroplastic Applications

A total of 1082 MaPs were distinguishable by origin, and 368 items were classified as ‘unknown’. The unknown items were organized by morphology type (Figure 3.6a). Of the total unknown items, fragments composed 83.4%, followed by foams (12.5%), fibres (1.9%), films (1.1%), and rubber (1.1%). Macroplastics that were able to be linked to a specific application are presented in Figure 3.6b. The most common application is “Smoking”, representing 42.5% of the total MaPs. Examples of items in this application are cigarette butts, coated filter papers, and lighters. The second most common application is “Food/Beverage Packaging”, which accounts for 18.3% of the total, and includes candy wrappers, bottle caps, bottles, lollipop sticks, drink lids, and packaging film. The “Narcotics” application (5.6% of total) is represented by syringes, saline solution bottles/caps, apothicom cups, and tourniquet bands. The “Packaging” application (6.0%) contains mini poly bags, sandwich bags, plastic bags, bubble wrap, and packing foam. The “Household” application (6.0%) is represented by push pins, toys, pens, electric hair trimmers, and clips. The “Medical” application (3.6%) contains pill bottle caps, medical packaging, surgical masks, prep pads, and pill bottles. Wire connector caps, nylon ties, tile spacers, stakes, tubing, and duct tape make up the “Construction” application (4.0%). The applications “Wrappers” (not food related) represent 2% of items.

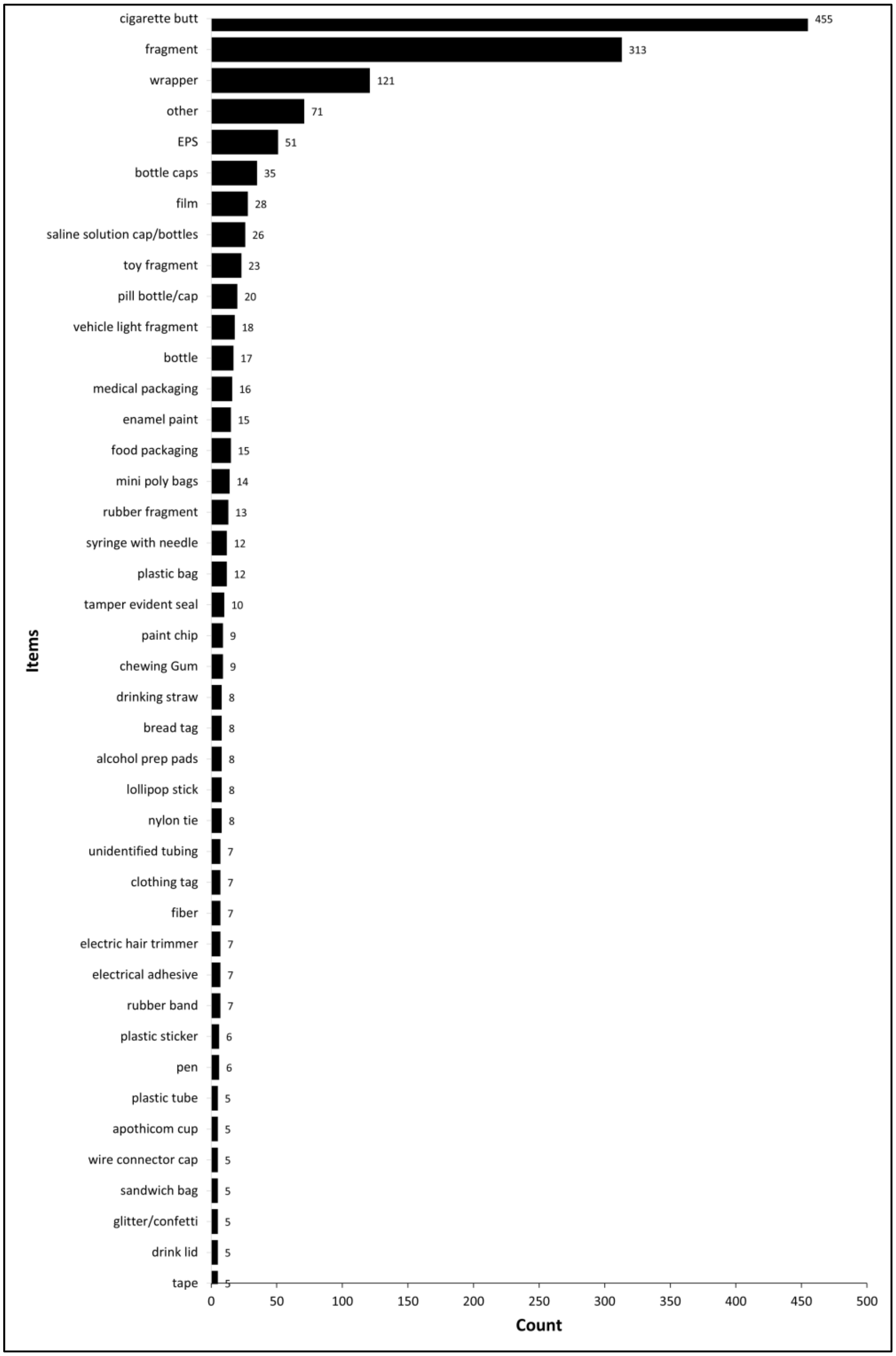

Figure 3-4. Visually identifiable MaPs in samples from all seasons and locations combined. Items constituting <5 of the total count are not displayed. These items include buttons (4), clothing labels (3), beads (3), lighters (3), plastic cutlery, and tourniquette bands (3).

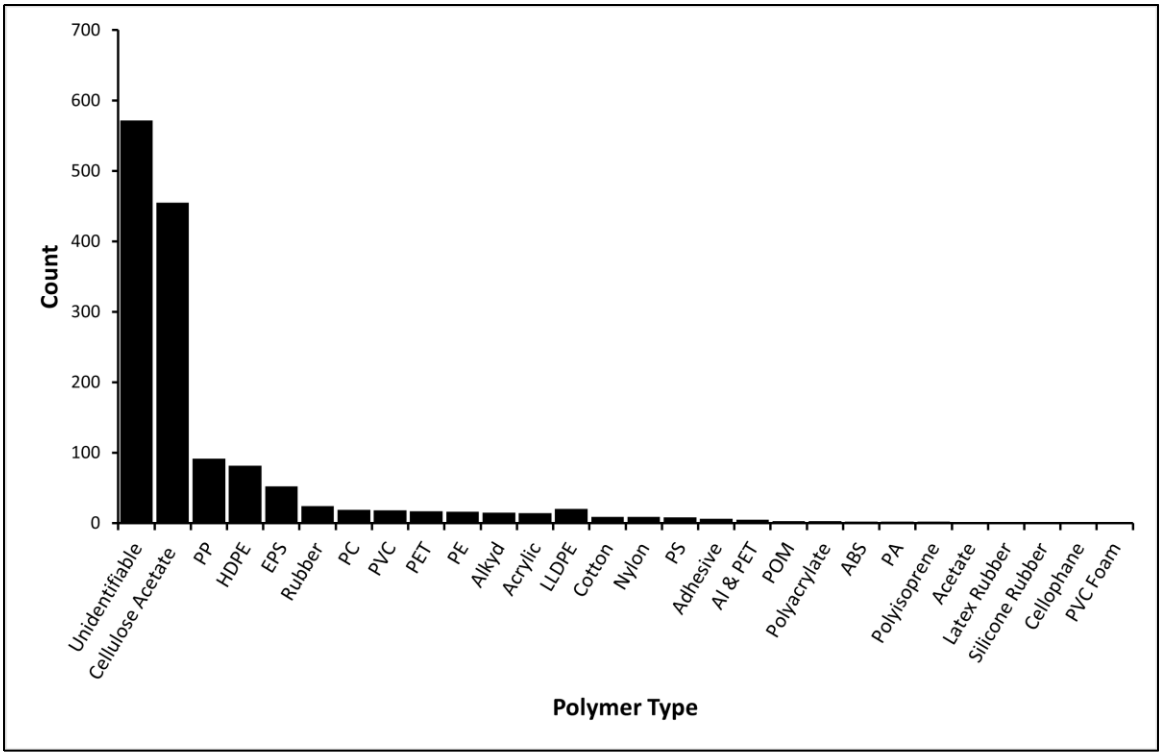

Figure 3-5. Macroplastic polymer types, as determined by the visual polymer identification process.

The remaining categories represent smaller numbers of MaPs: “Arts/Crafts” (pen, beads, glitter/confetti, glue stick - 1.8%), “Automotive/Transportation” (bike tubes, tire caps, vehicle lights- 2.3%), “Clothing/Textiles” (buttons, clothing tags, plastic zippers, aglets - 2.5%), “Food/Beverage” (chewing gum, drinking straws, cups, plastic cutlery - 1.8%), and “Industrial Coatings” (paint chips, enamel paints - 2.2%). The “Electronics” (electrical tape, cable tie, ear bud cover) application represents the smallest proportion of the total, contributing only 1.2%.

3.2 Microplastics

3.2.1 Microplastic Quantification

Similar to the macroplastic proportions, the greatest microplastic counts were in samples from the Bathurst, Dufferin, and Inner Queens sites (Figure 3.7). Of the Bathurst samples, the majority of MPs were found in the autumn sample (144 particles), followed by the spring (136 particles), summer (131 particles), winter (93 particles), and standard (29 particles) (Figure 3.8). The Carfrae site showed a similar trend, with the lowest number of MPs in the standard (11 particles). The highest microplastic count was in the winter sample (139 particles) followed by the spring (88 particles), autumn (35 particles) and summer (18 particles). Similarly, Dufferin displayed the lowest microplastic count in the standard (26 particles), whereas the winter sample contained 359 particles, followed by the summer (144 particles), spring (111 particles), and autumn (75 particles) samples. Samples from the Inner Queens site contained, in descending abundance, 213 particles (summer), 195 particles (autumn), 83 particles (spring), and 72 particles (winter). The Ivey site had low microplastic counts throughout all seasons. The highest count was recorded from the spring sample (67 particles), followed by the summer (32 particles), winter (26 particles), standard (6 particles), and autumn (3 particles) samples. The Outer Queens site contained relatively consistent microplastic counts across the seasons, with the highest count in the summer sample (80 particles), followed by the autumn (54 particles), winter (53 particles), spring (41 particles), and standard (8 particles).

3.2.2 Microplastic Morphologies

Microplastics were categorized into several morphologies, including fragments (unidentifiable source), intact fragments (identifiable source), foam, films (thin, flexible plastics), rubber-like particles, fibres, textiles, and non-plastic particles (Figure 3.9). Fragments were the most common morphology of microplastic, accounting for 45.0% of the total MPs. Foams and fibres were also widespread, comprising 23.3% and 15.4% of all MPs. Rubber-like particles, films, and intact fragments (e.g., beads) accounted for 7.7%, 6.4%, and 1.8% of the total, respectively. Non-plastic items represented 4.7% of the particles overall.

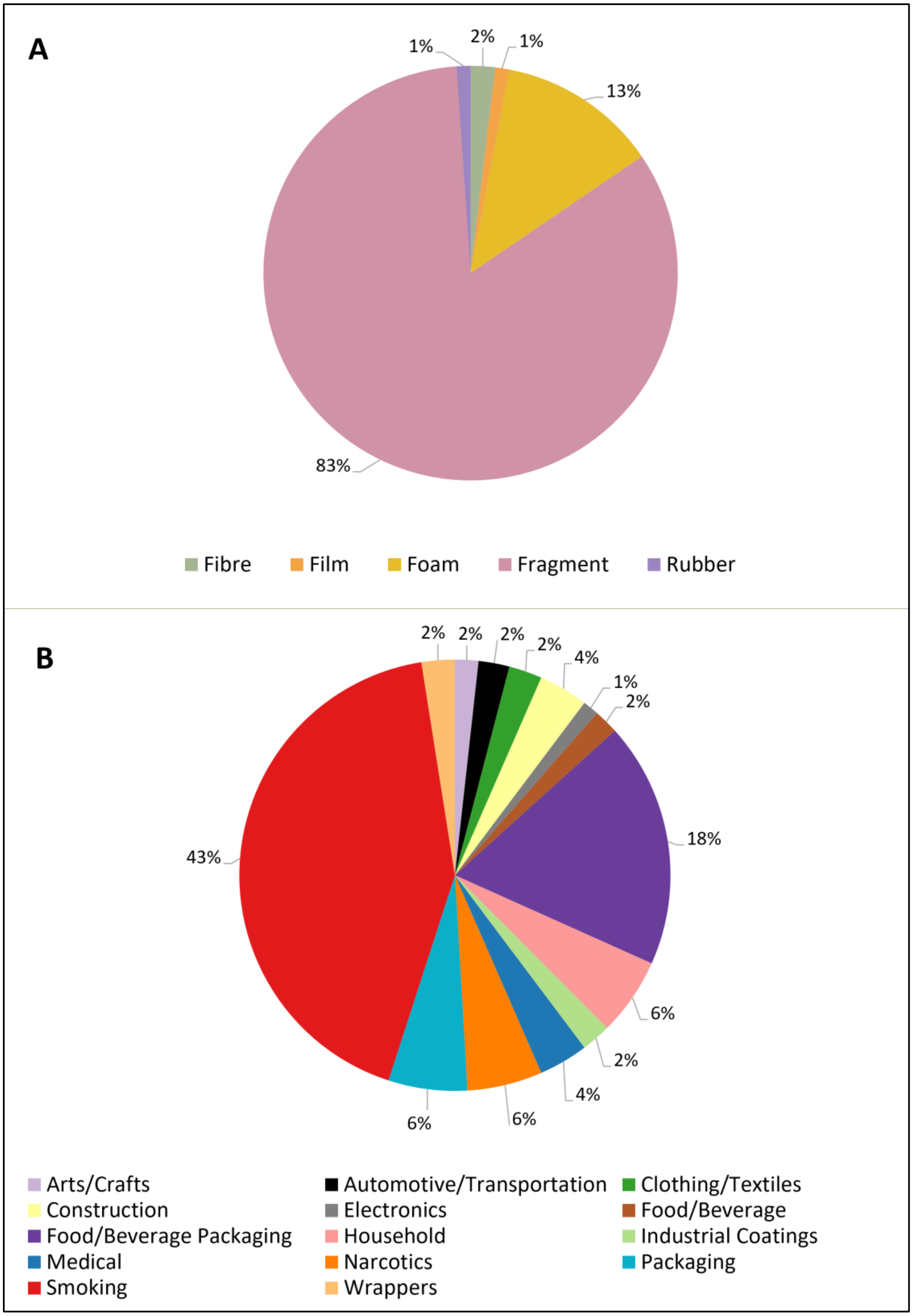

Figure 3-6. Classification of macroplastics. (A) Unknown items according to morphology, and (B) known macroplastic items grouped into common applications.

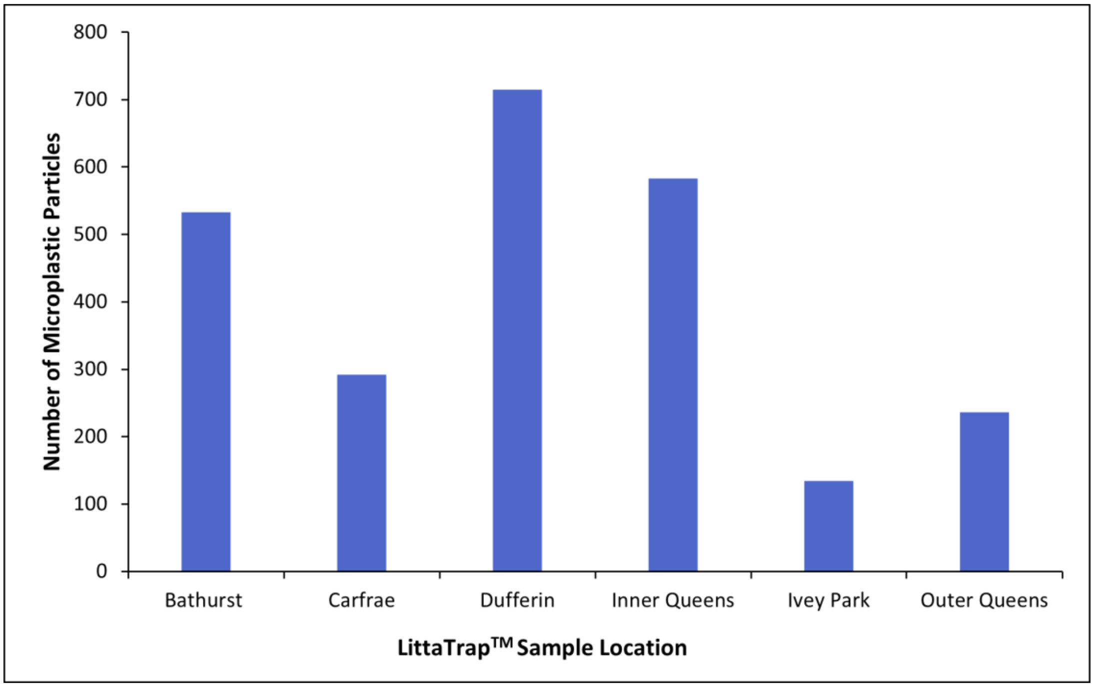

Figure 3-7. Total Count of MPs from each site combined across all seasons.

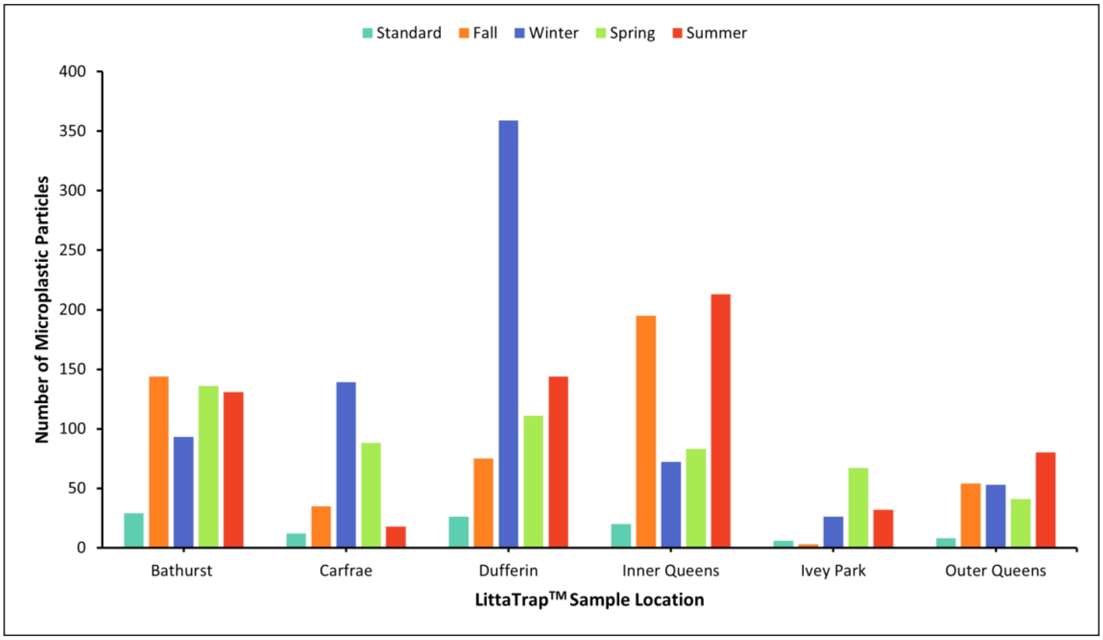

Figure 3-8. Seasonal abundance of microplastic debris found in the 1 mm mesh compared with the standard sampling period debris from the 5 mm mesh.

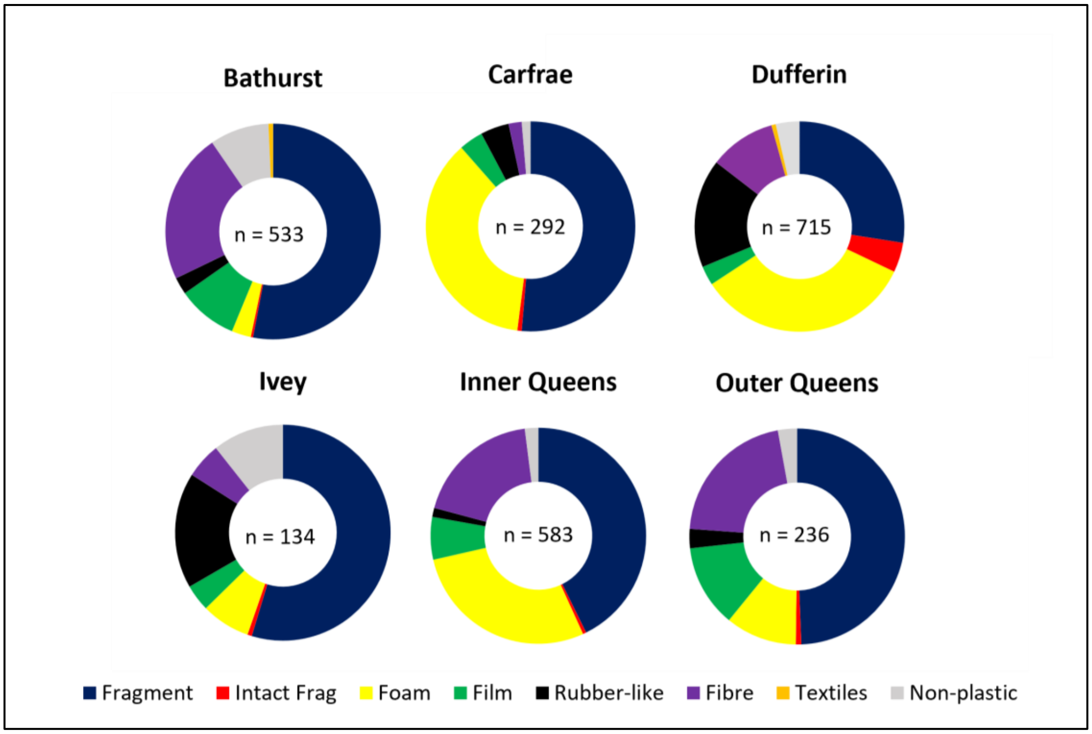

Figure 3-9. Relative percentages of microplastic debris morphology in each sample across all seasons.

The relative number of particle types in samples were obtained from each site. Of the six sites, the highest count of fragments was in the Bathurst samples (310 particles) and lowest in the Ivey samples (82 particles). Foam particles were most abundant in the Carfrae samples (250 particles) and least abundant in the Ivey samples (11 particles). Intact fragments were most prevalent at the Dufferin site (34 particles) and least common at the Ivey site (1 particle). The Bathurst samples contained the highest concentrations of films (53 particles), and Ivey the lowest concentration (6 particles). Rubber-like particles were most common in the Dufferin samples (124 particles) and least common in the Outer Queens samples (7 particles). Fibre counts were greatest in the Bathurst samples (132 particles) whereas fibres were least common in the Carfrae samples (6 particles). Textiles were found at only two sites, with 5 particles in the Dufferin and 4 particles in the Bathurst samples. All samples contained non-plastic particles, but the Bathurst site contained the greatest number (52 particles) and the Carfrae site contained the fewest (4 particles).

3.2.3 Microplastic Polymers

A total of 206 MPs were selected for FTIR using a random number generator (Figure 3.10). The most common polymer was PE (59 particles). Polypropylene was the second most abundant polymer (46 particles). Seventeen particles were composed of PET, commonly used in plastic drink bottles and synthetic fibres. Polystyrene, commonly used in the production of food packaging and insulation, was determined for 9 particles. Nine particles of acrylic were also detected (Figure 3.11). Other polymer types in relatively lower quantities were PVC (7 particles) and acrylonitrile butadiene styrene (ABS – 5 particles). The polymers POM, polyvinyl acetate, PVC, PES, urea resin, PLA, PE & PP (combined in one particle), acrylic resin, and polybutadiene each had a count of 1. Twenty-two particles were identified as non-plastics (cellulose, ethyl cyanoformate, dodecane, cashmere, hair, and cotton). Some black particles were visually indicative of rubber or were not infrared active, making their precise identification challenging.

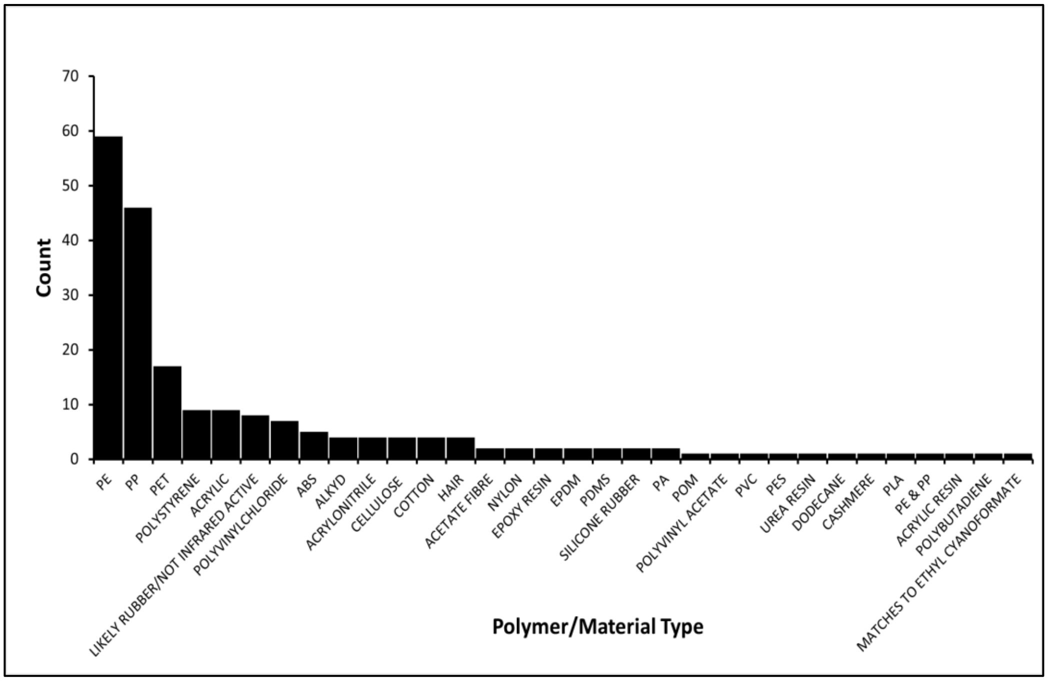

Figure 3-10. Microplastic polymers, as determined by FTIR spectroscopy of 206 randomly selected particles.

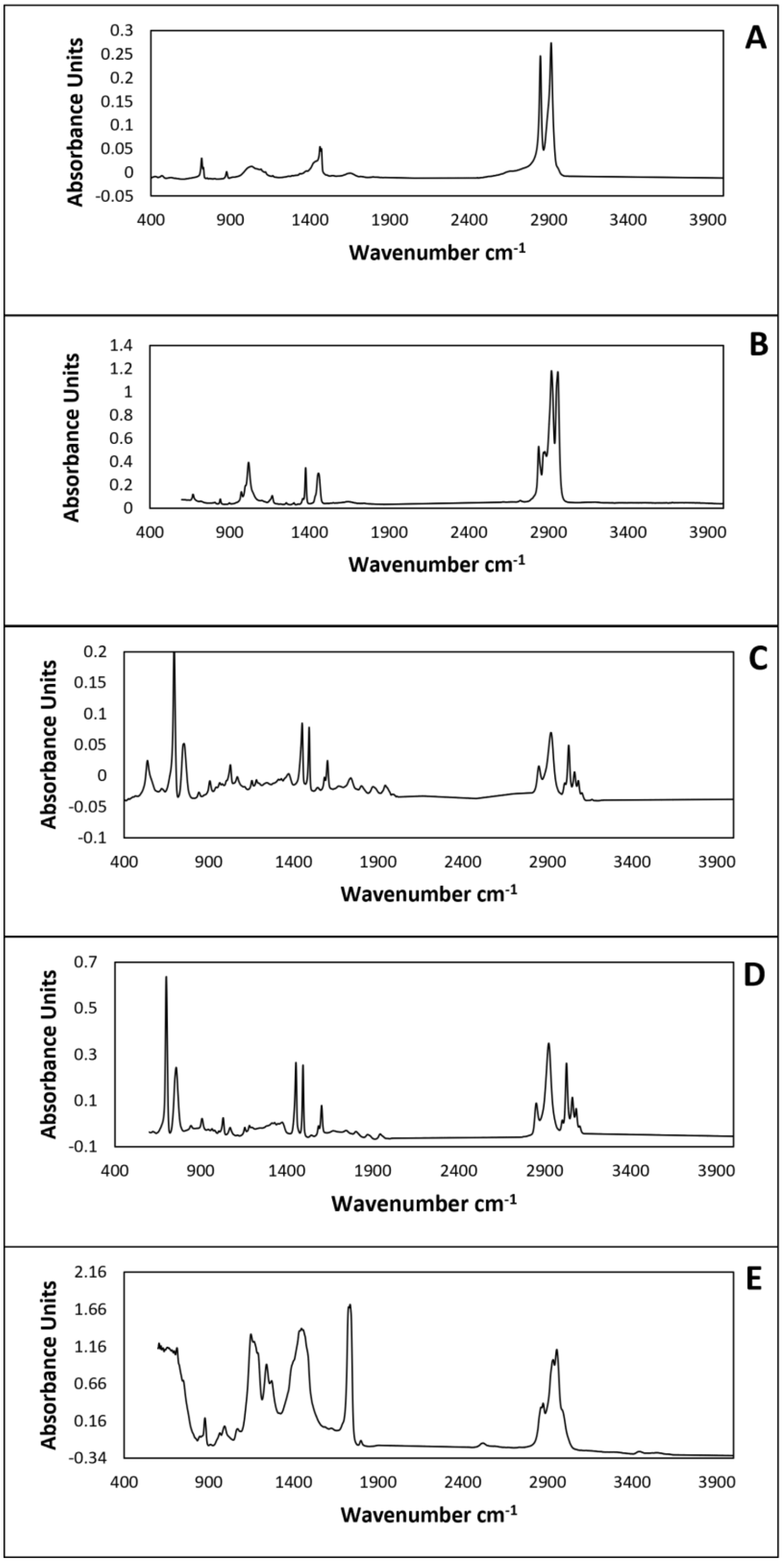

Figure 3-11. FTIR spectra of the five main types of MPs retrieved from all stormwater drains. (A) PE, (B) PP, (C) PET, (D) PS, and (E) acrylic.

3.2.4 Microplastic Colours

In this study, each microplastic particle was examined for colour (Figure 3.12). Microplastic colours are often overlooked, but they can affect the number of MPs found in the environment. Colour can have an impact on polymer photoaging, can indicate the way in which a microplastic was formed, and its perception can lead certain organisms to mistake MPs for food sources (Zhao et al., 2022). White MPs were most common at 29.2% (n=817), followed by black (13.5%; n=404), and blue (12.5%; n=373). Red particles accounted for 10.5% (n=313) of the total, followed by translucent (8.6%; n=256), and transparent (8.6%; n=261). There were moderate counts of green (4.5%; n=136), pink (4.3%; n=129), yellow (3.4%; n=102) and grey (2.7%; n=82) MPs. The least representative colours were orange (0.8%, n=24), purple (0.4%, n=12), and brown (0.3%, n=10). Colourless, iridescent particles represented 0.5% (n=16) of the total MPs.

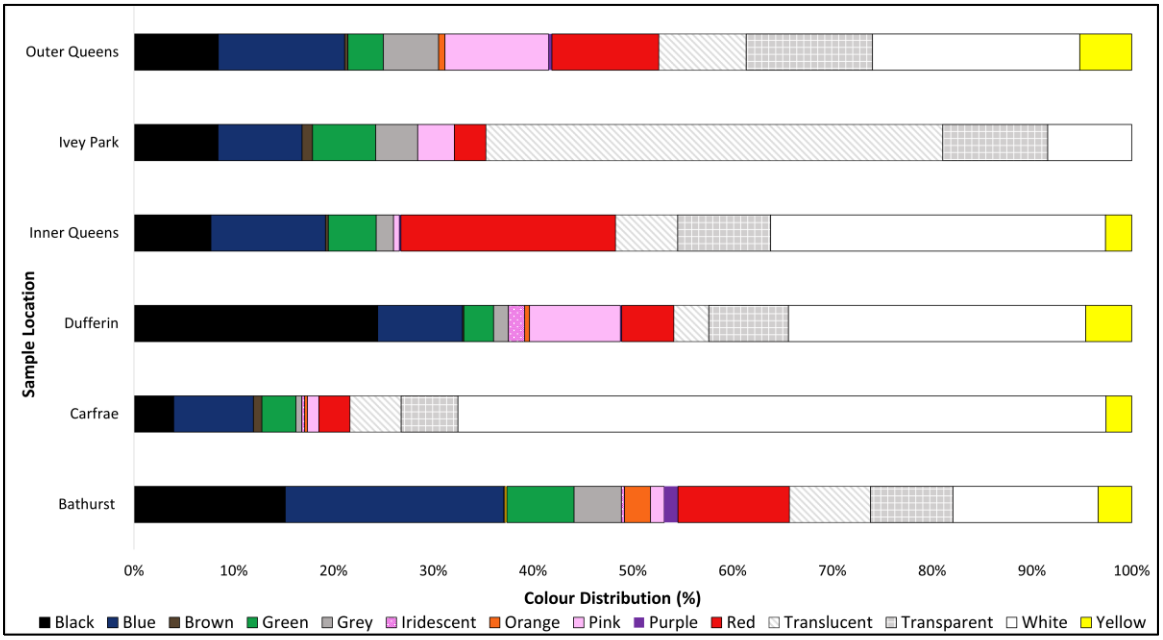

Figure 3-12. Graph showing the relative percentages of colours of microplastic particles from samples at each location (seasons combined).

4 Discussion

The movement of urban plastic debris into aquatic systems has been considered to be controlled by the number of humans and their activities, as well as weather conditions, such as precipitation amount and wind speed (Tasseron et al., 2023). The environmental factors are heavily controlled by seasons, particularly in locations such as London, Ontario, that have a temperate climate. The model in Figure 4.1 was created in order to illustrate the flow of stormwater through London's urban core into the Thames River. The flow path, illustrated by red arrows, indicates the direction that plastic debris in run off would travel. Plastic debris sources and pathways also include roads, parks and residential areas, commercial and services buildings, apartments, industries, and parking lots. Areas with high pedestrian traffic including social service buildings (e.g., homeless shelters, soup kitchens), schools, and parks contribute plastic litter to stormwater drains. Litter is mainly produced from human activities during the warmer months. Although precipitation and windspeed may affect transportation rates of plastic pollutants, the urban core contains many anthropogenic structures that could block or redirect their flow.

4.1 Number of MaPs and Seasonal Variation

Macroplastics found in samples from six different locations in London, Ontario across four seasons revealed notable variations, which highlights the complex nature of plastic pollution in the environment. The following evidence suggests that there is a seasonal pattern in macroplastic accumulation, with the most pronounced means recorded during the summer and spring, followed by autumn and winter (Figure 4.2). Increased input of plastic debris during the spring and summer can be attributed to greater pedestrian traffic, increased outdoor activities with more single-use plastics (SUPs), and release of items during the spring snowmelt. Eslami et al. (2023) also concluded that the summer months generate the most waste due to vacations and social gatherings.

4-1. A model of the various sources, routes, and barriers that could affect the transport, amount and types of plastic debris items accumulating in downtown London stormwater drains.

The standard samples (mesh size of 5 mm) were collected from each site on October 25th to compare with the autumn samples (mesh size of 1 mm), which were collected on December 16. The Dufferin, Inner Queens, and Ivey Park standard samples contained greater numbers of MaPs compared to the autumn samples, with 1.4 times, 2.0 times, and 2.4 times the number of items in the former compared to the latter. The results could be due to temperature changes, as the 22-day standard collection period had an average daily temperature of 14°C, whereas the average daily temperature of the autumn collection period was 2°C (London Weather Stats, 2023). The colder autumn temperature period may have led to lower numbers of individuals on the city streets, which in turn would have decreased the influx of plastic waste items into the storm drains. In contrast with the three other sites, the Bathurst and Outer Queens autumn samples contained 2.6 times and 3.3 times the number of MaPs compared to their standards (Figure 3.2). These results indicate that temperature alone cannot account for the relative number of MaPs across all sites. The Carfrae site also contained more MaPs in the autumn sample (11) compared to the standard (7), but given the small number of items, this is not considered a significant difference.

The number of MaPs was compared with the average wind speed for each 22-day period (London Weather Stats, 2023) (Figure 4.3; Appendix 2). A Pearson correlation coefficient (r) of -0.154 and a p-value of 0.41 were determined, indicating a negligible correlation between average wind speed and number of MaPs. Each 22-day period may not have captured these correlations, indicating the complexity of variables in urban locations.

The relationship between the number of MaPs and the total amount of precipitation during each 22-day period was also considered (London Weather Stats, 2023) (Figure 4.3; Appendix 2). During the autumn sampling period, there were 274 items across all six sites, with a precipitation total of 72.7 mm (Figure 4.4). The 22-day accumulation period for the standard samples produced 222 items, with a precipitation total of 115.8 mm. A greater amount of precipitation was expected to lead to a higher number of MaPs in stormwater drains, but samples from all sites and seasons differ significantly from the standard as well as from one another. With an r of 0.05 and a p-value of 0.77, there is no statistical correlation between precipitation and macroplastic abundance. A lack of correlation between precipitation and MaPs may be explained by diverse stormwater runoff characteristics, wherein flow direction and intensity, land-use, and drainage systems can influence deposition. Bauer-Civiello, 2019) studied plastic debris items that were transported from urban storm drains into a tropical river in Australia and found that fewer debris items were found during the wet season than in the post-wet season. The authors suggest that the frequency at which plastic and other debris items accumulate may be dependent on variance in rainfall rather than total amount. In addition, item transport mechanisms are complex and could cause debris to adhere to rough surfaces such as vegetation and soil, compared with asphalt.

4.2 Number of MPs and Seasonal Variation

The number of MPs in samples from all sites and sampling periods was compared (Figure 4.5). Comparing macroplastic data in Figure 4.3 to microplastic data in Figure 4.5 indicates a similar pattern wherein the mean concentrations of MPs are greatest in the summer samples, followed by lower concentrations in the spring, autumn, and winter samples. These findings suggest that there is a consistent seasonal variation in plastic accumulation.

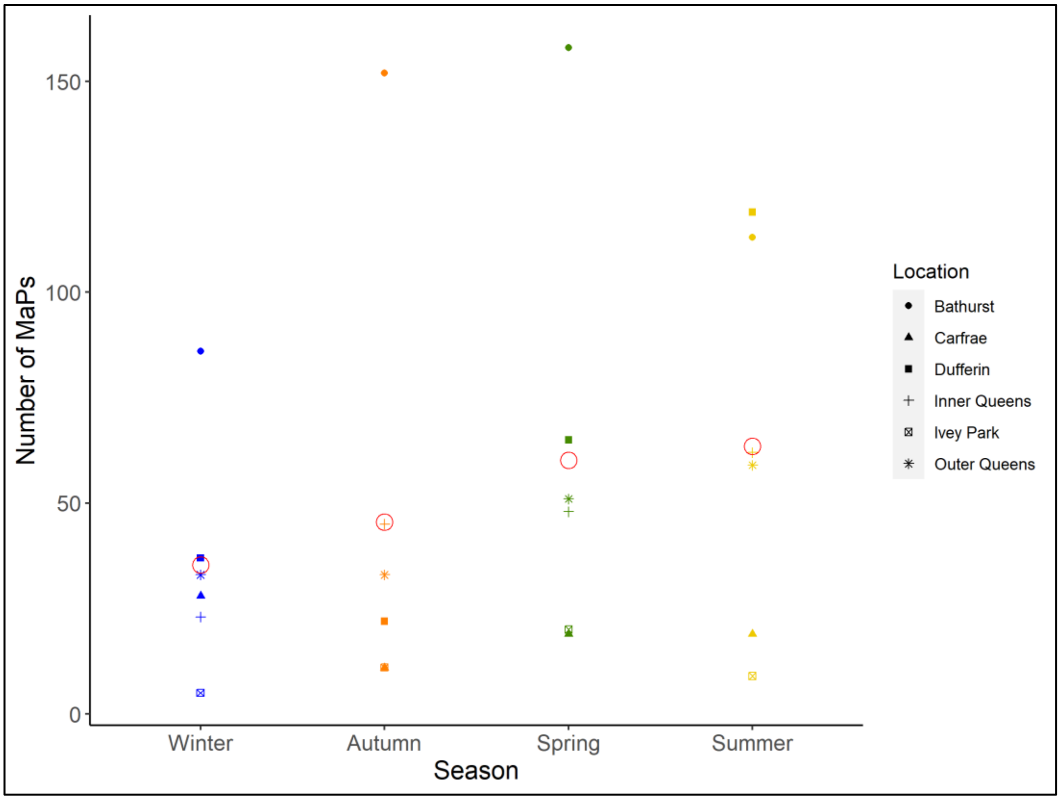

Figure 4-2. Calculated means (red, open circles) of MaPs for each sample location and each season.

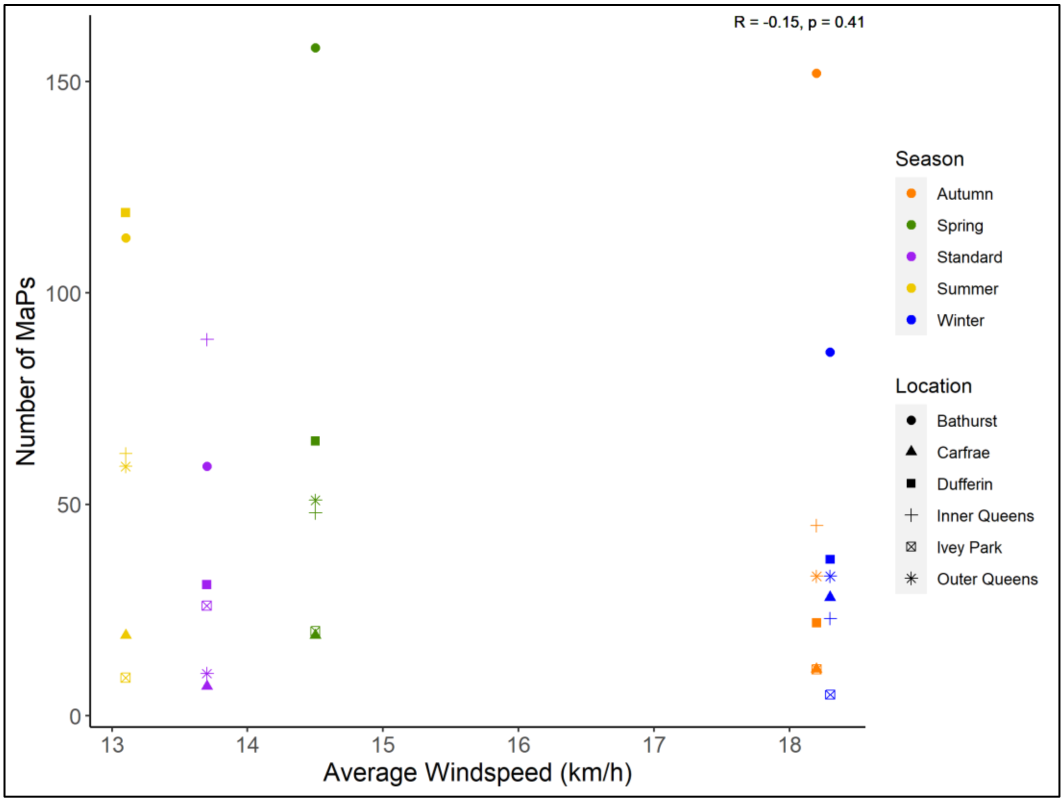

Figure 4-3. Relationship between average windspeed (km/h) and number of MaPs in samples from every sampling period and site.

The number of MPs in each sample was compared with the average wind speed for each 22-day period (Figure 4.6; Table S2). There was no correlation found between the two variables (r = 0.216; p-value = 0.25). A comparison was also made between the amount of MPs in each sample and total precipitation during each season (Figure 4.7). A greater amount of precipitation is expected to lead to a higher number of MPs (Axelsson and Sebille, 2017; de Jesus Piñon-Colin et al., 2020). However, all sites, except for Ivey Park, contained greater numbers of MPs in the autumn samples compared to the standards, which would not be expected if abundances were controlled by amount of precipitation. This may be explained by routine maintenance and cleaning of urban areas through city efforts. At Ivey Park, the regular use of the splash pad in warmer months allows for increased of flushing of plastic particles into the storm drain.

A total of 115.8 mm of rain fell during the standard sampling period, whereas 72.7 mm of rain fell during the autumn sampling period. The seasonal precipitation totals were compared with the total number of MPs in each sample from all sites and no correlation was determined (r = -0.166; p-value = 0.38).

In summary, although the data indicate an overall seasonal effect on both macroplastic and microplastic debris abundances in city stormwater drains, this effect is not a function of average wind speed nor total precipitation during each sampling period.

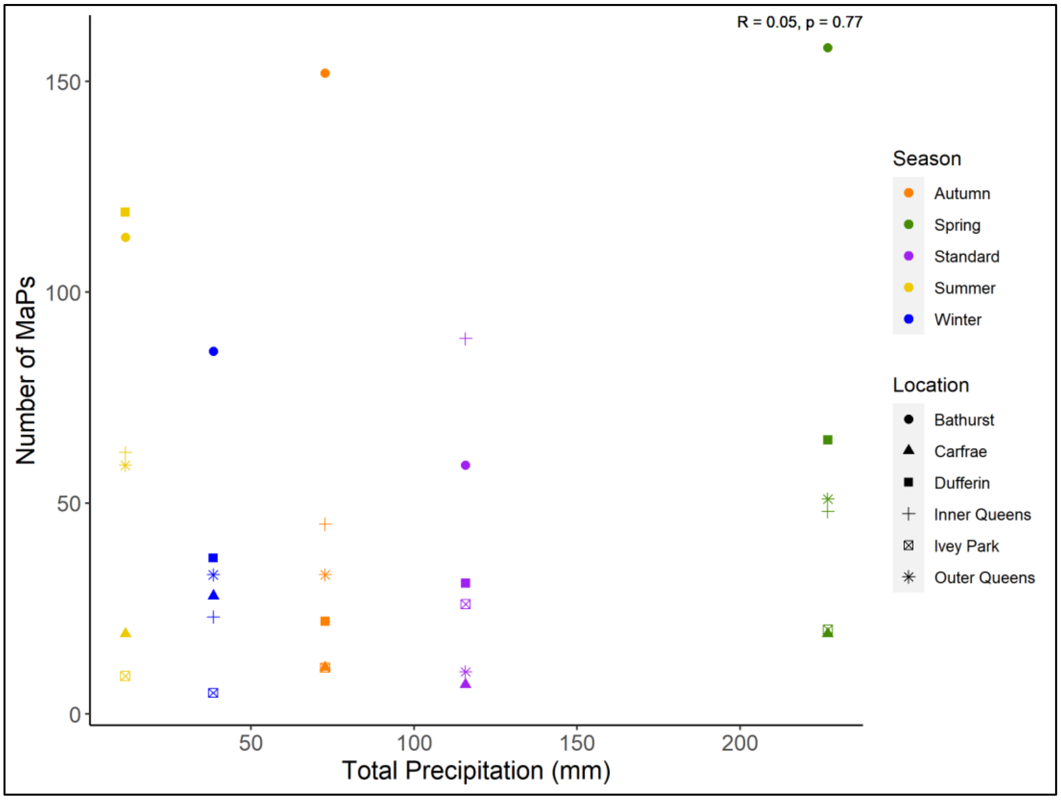

Figure 4-4. Relationship between total precipitation (mm) and number of MaPs for every season and site.

4.3 Human Influence on Number of Plastics

The population of London grew by 5.1% between 2015 and 2020 and is forecasted to grow by another 5% from 2020 to 2025 (Watson & Associates Economists Ltd., 2022). With population growth, a forecasted increase in retail and commercial spaces will follow. These increases will cause greater pressure on stormwater management systems, as they divert run-off and associated debris into urban drains. The debris, which is largely composed of plastic, will increase and items will be washed into the Great Lakes watershed. Of all sampling sites, the Dufferin location was expected to contain the highest amounts of plastic debris, as it is located near a busy main road and a frequented park in the downtown core. This was the case for MPs, but not for MaPs, which were most abundant overall in the Bathurst samples. This may be a result of the Bathurst site's proximity to a Salvation Army shelter and community centre. The area has heavy pedestrian traffic, which is associated with greater littering of trash. In contrast, the Dufferin site contained a notably high number of MaPs in the summer sample only. This result can be explained by the increase in outdoor activities (e.g., festivals, road races) and pedestrians in the central downtown area where the Dufferin site is located, during the summer.

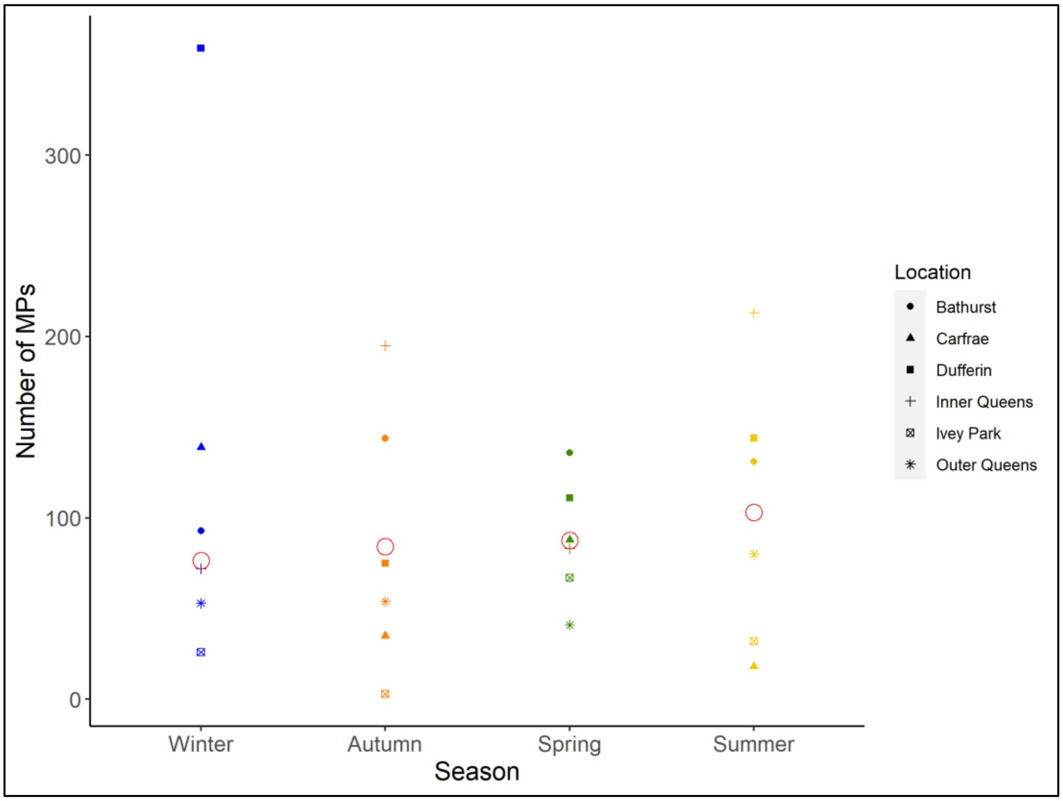

Figure 4-5. Calculated means (red, open circles) of MPs for each sample location and each season.

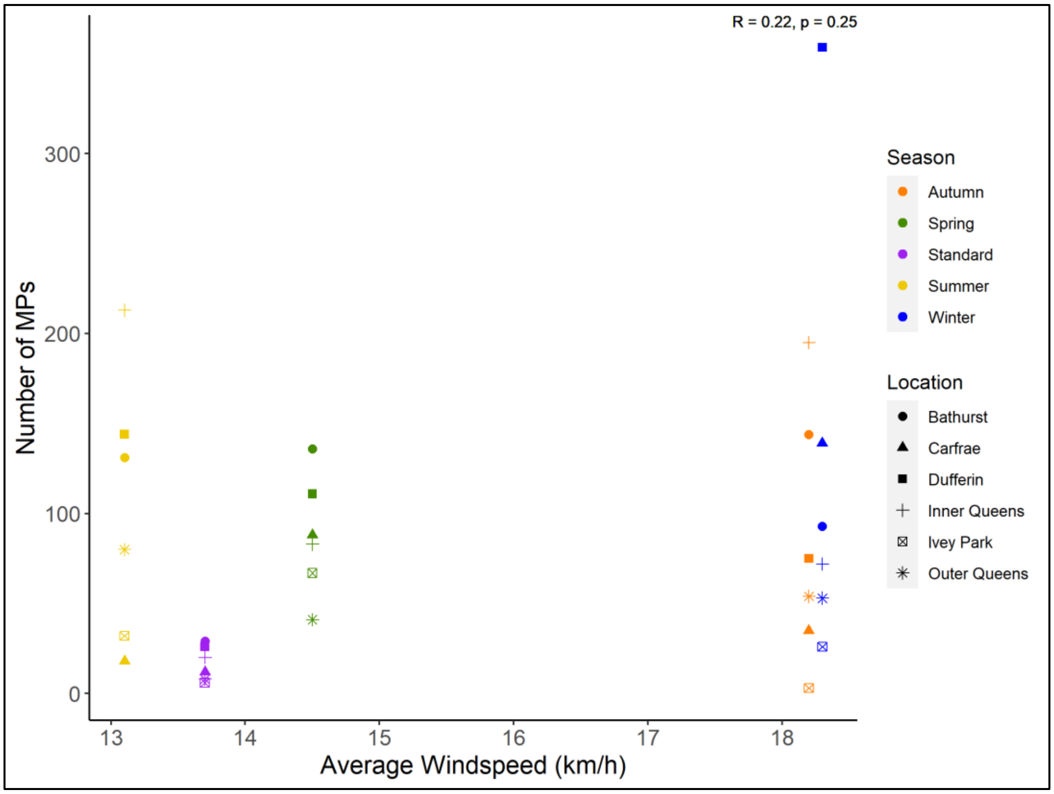

Figure 4-6. Relationship between average windspeed (km/h) and number of MPs in samples from every season and site.

The Inner Queens and Outer Queens sites are located in the same parking lot, and except for the standard samples, the macroplastic abundances are similar, but the number of MPs between sites is not. The variations between the number of MPs captured from the two sites could be due to the location of the Inner Queens drain in the center of the parking lot rather than at the lot's corner where the Outer Queens site is situated.

The Carfrae site is in a residential area and thus, it was correctly hypothesized that fewer MaPs would be found at this location. It was also the site with the third fewest number of MPs. Similarly, the Ivey Park site contained very little plastic debris, with the lowest counts of MaPs and MPs overall. This result was also anticipated because it is in the middle of a children's splash pad. The lowest number of MaPs and MPs at Ivey Park were collected during the summer sampling period, which coincides with the greatest use and regular cleaning of the splash pad for health and safety purposes.

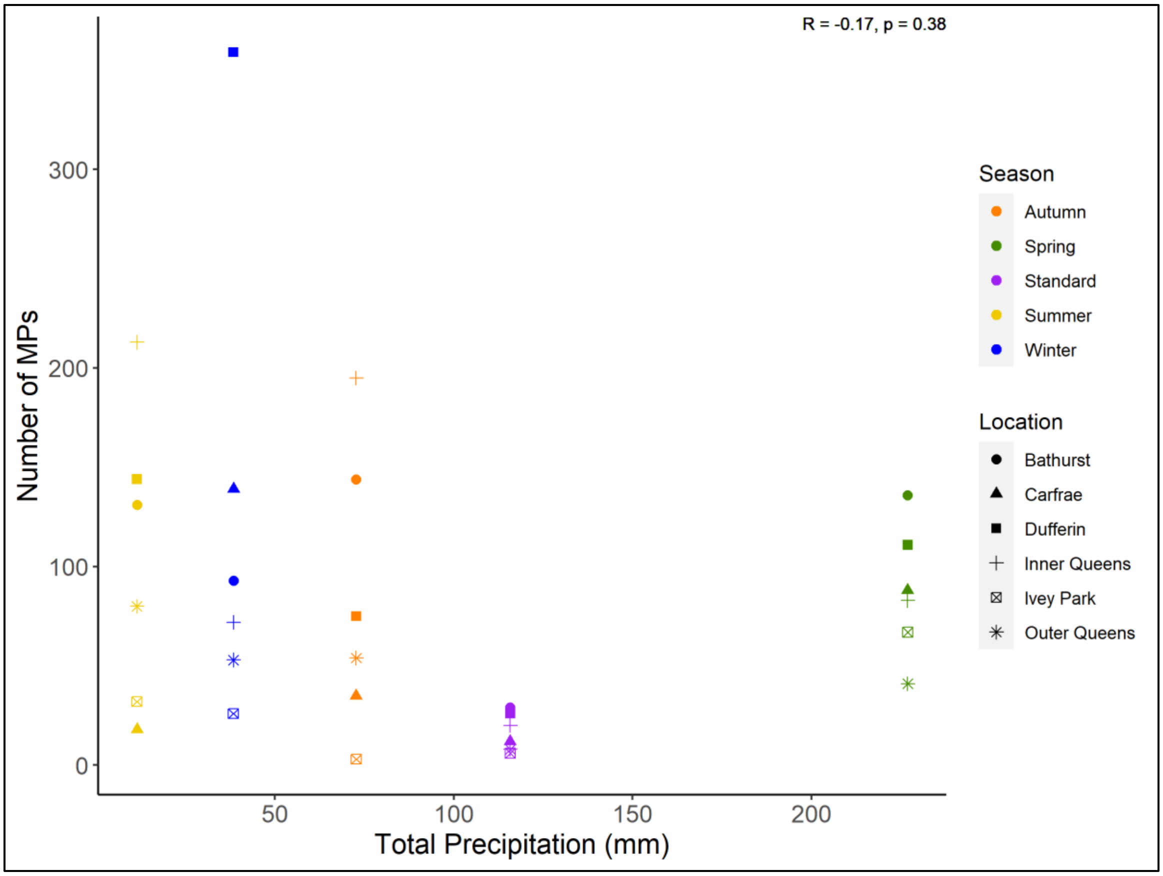

Figure 4-7. Relationship between total precipitation (mm) and number of MPs for every season and site.

4.4 Effectiveness of 1 mm vs 5 mm LittaTrap^{TM}

A comparison of the autumn (>1 mm) and standard (>5 mm) samples revealed no correlation for MaPs, but the numbers of MPs at all but Ivey Park were greater in the autumn sample than in the standard. The Ivey Park sample, however, contained only 6 particles in the standard and 3 particles in the autumn sample, which may not be a statistically reliable number. The results indicate that the 1 mm mesh in the Litta Trap was 5.0, 3.0, 3.0, 9.8, and 6.75 times more effective at capturing microplastics in the Bathurst, Carfrae, Dufferin, Inner Queens, and Outer Queens samples, respectively, than the 5 mm size mesh. Greater capture effectiveness was anticipated because, by definition, MPs are <5 mm in size. The 5 mm mesh did capture some MPs, but mainly through entanglement with organic debris or blockage of the mesh with MaPs. Implementing the finer 1 mm mesh demonstrated that no additional maintenance was required, as evidenced by the absence of reported flooding at the sample sites. However, this may not be the case if the finer mesh size is used in other urban centres.

4.5 Potential Sources

The predominant macroplastic waste items trapped in the stormwater drains included cigarette butts, wrappers, EPS foam, rubber, paint products/industrial coatings, and narcotics paraphernalia. Similarly, the most frequently found items in the Global Ocean Trash Index and the Great Canadian Shoreline Cleanup (GCSC) are cigarette butts, food packaging, and EPS foam (Ocean Conservancy, 2023; Ocean Wise, 2023).

It is estimated that over 4 trillion cigarette butts, composed of cellulose acetate, are littered each year globally (Webler & Jakubowski, 2022) All sample sites contained cigarette butts, with the highest proportions found in the Bathurst (177; 38%) and Outer Queens (65; 14%) samples. The predominance of debris representing the “smoking” application in this study are associated with the most common item found (cigarette butts), representing 42.5% of all MaPs identified. This finding is consistent with the observations made by Healton et al. (2011), in which cigarettes accounted for 25-50% of all litter collected from roads and streets. This similarity in findings indicates a widespread and systematic issue with the disposal of smoking-related items in public spaces.

Wrappers, which belong to the “food/beverage packaging” application, represent 18% of the total items identified in this study. Such findings reaffirm the growing issue of food packaging waste in the environment. According to PlasticsEurope (2020), 40% of plastic production is dedicated to food-related packaging. Furthermore, the World Economic Forum (2016) estimates that 95% of food packaging is thrown away after a single use. This trend of single use plastics in food packaging is driven by the demand for convenience by the consumer, low cost for the supplier, and lengthened preservation of the product. Foams, which are the third most common plastic items found in this study and in the GCSC and Global Trash Index, are also used in packaging of not only food items, but also for products such as electronics and crafts.

Rubber-like particles were found at four of the six locations (Carfrae, Dufferin, Inner Queens, and Ivey) (Figure 4.8a). Black, rubber-like MaPs form part of the “automotive” application, which comprises 4% of the total. One hundred and fifty-four black MPs were characterized as ‘rubber-like’ due to their elasticity and irregular margins. These types of particles have been identified in numerous studies of MPs across the globe (Baensch-Baltruschat et al., 2020). The presence of translucent rubber-like particles at the Ivey Park site could represent degraded silicone caulking sourced from within the park’s playground (Figure 4.9). These rubber-like particles belong to the “construction” application, which accounts for 4% of all macroplastic applications. The microplastic polymer compositions consistent with rubber include ethylene propylene diene monomer rubber (EPDM), silicone rubber, and polybutadiene.

The ‘Narcotics’ category represents 6% of the total items found in this study. Narcotics-related paraphernalia were identified in samples from the Bathurst, Dufferin, Inner Queens, and Outer Queens sites. This covered a broad range of items including sterile needle filters, syringes, syringe packaging, saline solution bottles, tourniquet bands, apothicom cups, and prescription bottles (Figure 4.8b). The Inner Queens site contained the most drug-related debris. While collecting samples from this location, we witnessed individuals actively involved in drug use and purchasing. The presence of narcotics-related items provides a key example of how public health and environmental issues intersect. Items like syringes and saline solution bottles may indicate both medical and non-medical drug use. The disposal of these items in the environment is not only a litter problem, but also a potential health hazard. Improperly discarded syringes may also cause injury.

Macroplastic items composed of enamel, silicone and paints were found in samples from five of the six sites (Carfrae, Dufferin, Inner Queens, Ivey, and Outer Queens), and form part of the “industrial coatings” application. Microscopic paint chips and coatings were also identified through FTIR as alkyds. Paint chips are common MPs identified globally (Gaylarde et al., 2021). The abundance of these particles in both MaPs and MPs of the present study is not surprising because most structures, signs, crosswalks, roads, and vehicles are covered with paints or coatings.

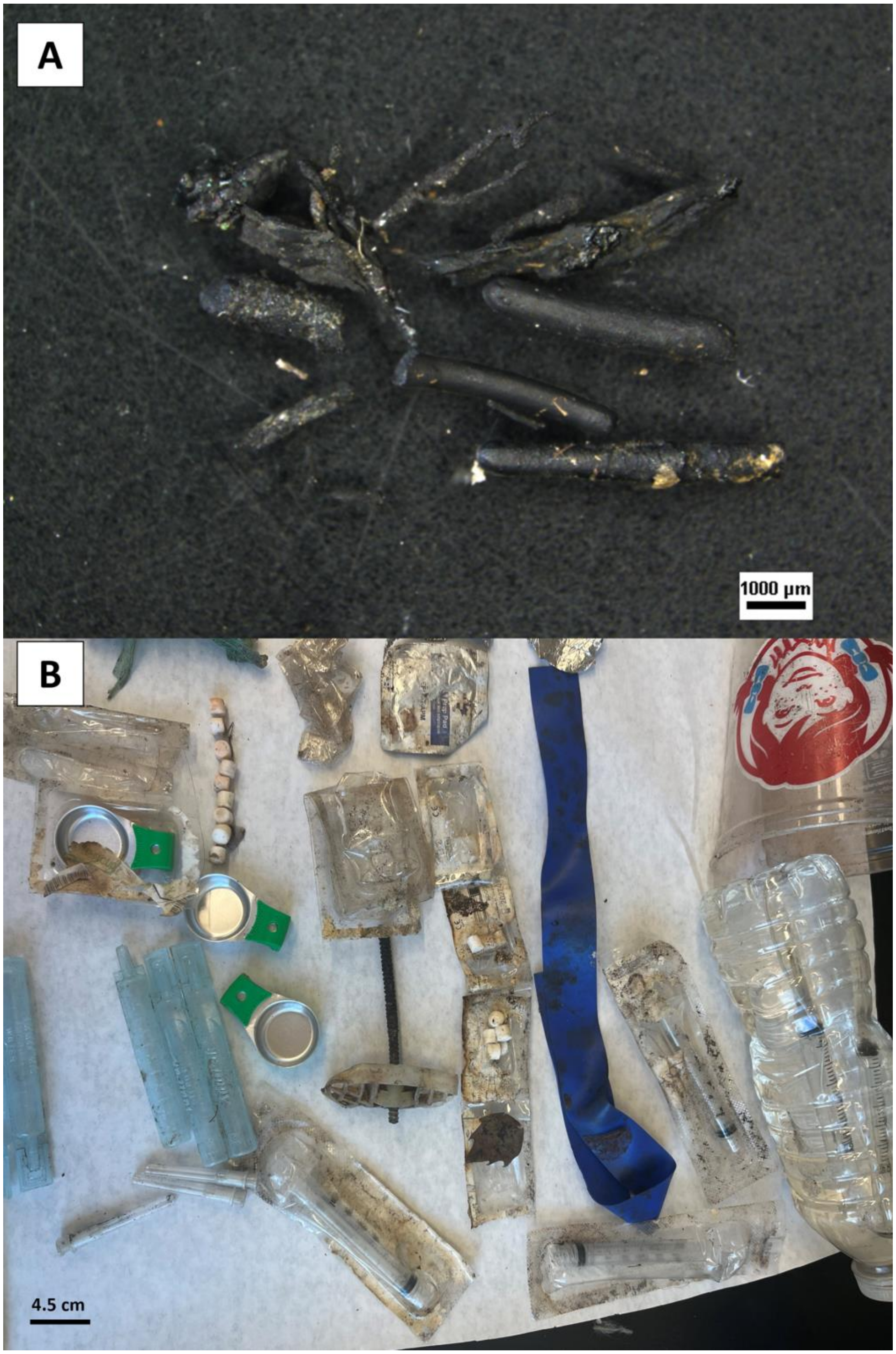

Figure 4-8. Applications linked to plastic debris in this study. (A) Rubber-like MPs. Black, rubber-like fragments are considered "automotive" as they may be tire-wear particles (Kole et al., 2017). B) Common 'Narcotics' related items found in the Bathurst summer sample.

Microplastic particles composed of epoxy resin, polyvinyl acetate (PVA), urea resin, dodecane, and acrylic resin could be included in the “construction” application. The MPs polyoxymethylene (POM) and polysulfone (PES) are known for their stability at high temperatures, as well as their high strength and rigidity. Items composed of POM are mainly high-performance engineering components common to the “electronics” and “automotive/transportation” applications. Polysulfone is a flame retardant that is used for a variety of applications, such as “household”, “electronics” and “medical”.

Microplastic colours can also help identify sources (Hartmann et al., 2019). In this study, white microplastics constituted the greatest percentage of MPs in the mesh liners (29.2%). Giacovelli (2018) considered the origins of white and transparent MPs found in stormwater to be derived from single use plastics and referred to these as “white pollution”. The majority of single use plastics are susceptible to fragmentation and easily degrade into smaller microplastic particles. Black MPs were the second most common colour of particles in the present study (13.2%), and some were rubber-like. Fragments and films considered “iridescent” had an opaline appearance and resembled glitter, particularly those with a hexagonal shape. Glitter is commonly used in decorations and cosmetics, and in the present stud is part of the “arts/crafts” application.

Figure 4-9. Transparent ‘rubber-like’ particles observed in Ivey Park samples, potentially originating from silicone caulking.

4.6 Campaigns to Halt Plastic Pollution

The creation of campaigns surrounding the issue of plastic pollution is an important strategy for raising awareness and calling for actionable responses from public and private sectors. The following section will discuss different campaigns that have influenced the movement on the reduction of plastic pollution globally as well as providing examples to be used in a collaborative effort with the City of London. The five types of campaigns are: (1) Public awareness, (2) Corporate, (3) Government-led, (4) Non-governmental Organization (NGO).

4.6.1 Public Awareness Campaigns

The perceived threat of plastic pollution has circulated for the past two decades because of its ubiquity in the natural environment and the extended media coverage it has received (Syberg et al., 2018; Bailey, 2022). This has led to the emergence of initiatives such as public awareness campaigns (PACs), which facilitate the engagement of individuals, businesses, industry, and governmental bodies through education on the threats and solutions related to plastic waste pollution (World Wide Fund For Nature (WWF), 2023). These campaigns are important in shaping public perception, and motivating actionable environmental measures aimed to produce positive changes for a community (Borawska, 2017). The overall objectives of PACs are to: (1) educate the public on the detrimental effects of plastic pollution, (2) encourage behaviour change through adoption of sustainable habits like reducing, reusing, and recycling, and (3) strive to influence and enact policy change (Borawska, 2017). Moreover, the impact of public awareness on environmental issues, as documented in Climate Change awareness (Wolf & Moser, 2011), stresses the effectiveness of successful outcomes when communities are well educated. A study conducted by (Oguge et al., 2021) analyzed the knowledge and attitudes towards SUPs in Kenyan youth and concluded that awareness campaigns are essential to close the gap between knowledge and practice.

The increase of public awareness and knowledge of plastic pollution can further influence the level of active participation in the community. For example, Plastic Free Schools is a program that aims to reduce the use of SUPs. In this program, campaigns and environmental educational programs promote sustainable alternatives for youth in hopes of influencing future generations (Plastic Free School, 2023) This organization provides resources on how you can implement your own campaign including links to external resources, such as Ocean Wise's Educator and Student Guidebooks for elementary, middle, and secondary school levels.

The success of initiatives like Plastic-Free July, led by the Plastic Free Foundation Ltd, demonstrates the power of PACs. This campaign encourages individuals to avoid SUPs, choose reusable packaging, and choose sustainable products throughout the entire month of July. Over the last few years this campaign has been steadily growing with increasing sign-ups, media coverage, and corporate participation. In 2022, 140 million participants made conscious changes to reduce their plastic consumption, resulting in a reduction of 2.6 million tonnes of plastic. Global recognition from major countries and companies indicates the success of this campaign. For example, the Indian government banned the use of 19 SUP items on July 1, 2022, and the Oman company, National Finance, was inspired to develop the 'Use Less Plastic' campaign as a response to Plastic Free July. These examples show how successful PACs can be in driving positive change on a global scale (Plastic Free Foundation, 2022)

4.6.2 Corporate Campaigns

Corporate campaigns approach plastic pollution efforts with a duality of business-wide waste reduction while also encouraging consumers to adopt eco-sustainable practices. Industry actions must be accountable, and initiatives through Corporate Social Responsibility (CSR) can influence society by demonstrating responsibility for societal and ecological footprints ((Landon-Lane, 2018). Through CSR programs, companies can contribute to community development, environmental conservation, and ethical business practices. Many companies that implement CSR initiatives have enacted positive change, most notably in the area of sustainability, by reducing or redesigning products that are 'greener' (Le, 2022) (Table 4-1). For example, the companies Adidas and Garnier have aimed to design packaging/materials with compostable/biodegradable materials instead of virgin plastic, thereby reducing the amount of plastic that ends up in landfills and oceans. Other companies carry out recycling programs to promote a circular economy, such as

Dell Technologies. Corporate campaigns and green initiatives solidify a company's commitment to sustainability, which has the power to change societal behavior and set the industry standard.

4.6.3 Government-led campaigns and Initiatives

Globally, governments have recognized the urgency and demand regarding plastic pollution initiatives. Many countries have created and implemented government regulations and restrictions to limit the input of plastic waste entering the environment through reduced plastic manufacturing and consumption (Willis et al., 2018). Several governments have launched campaigns aimed to shift behavioral tendencies towards plastic products by emphasizing the urgency of plastic waste management (Table 4-2).

A regional example is how the Canadian government, as of June 2018, banned the manufacture, import, and sale of toiletries used to exfoliate or cleanse using plastic microbeads or any particle used in toiletries less than 5 mm in size (Department of Justice Canada, 2017). Schedule 1 of the Canadian Environmental Protection Act, 1999 (CEPA) has been recently updated (2021) to include "plastic manufactured items" in order to regulate and carefully manage plastic products. The CEPA contains laws for preventing pollution and protecting the natural environment. There are several tools that address plastic pollution at different stages, for example, during manufacture, import, sale, use, and disposal (Canada Gazette, 2021). In June 2022, ECCC published the *Single-use Prohibition Regulations* in which 6 categories of single-use plastics were marked for prohibited manufacture, import, and sale (ECCC, 2022). In addition, the Canadian government has created a campaign, the Zero Plastic Waste Agenda, which is composed of two phases. Phase 1 identifies actions to improve the circularity of plastics in the economy and make the system change needed to reduce plastic waste. Phase 2 outlines actions to reduce plastic pollution, raise awareness, strengthen science and take a global stance on implementing timelines to prevent, reduce, reuse, recover, capture, and clean up plastic pollution in Canada. However, as of November 2023, despite these regulations, court decisions claimed that the Single-use Prohibition Regulations are "unreasonable and unconstitutional" due to the broad classification of polymers as toxic substances. Such legal decisions display the complexities between politics and plastics regulations.

Table 4-1. Examples of corporate campaigns with missions and goals towards sustainable materials and a 'greener future'.

Company	Mission/Goal	Initiative/Campaign
Carlsberg Group https://www.carlsberggroup.com/sustainability/our-esg-programme/zero-packaging-waste/	**By 2030:** 100% recyclable, reusable, or renewable packaging. 90% collection and recycling rate for bottles and cans. 50% reduction of virgin fossil-based plastic. 50% recycled content in bottles and cans.	Focus on circular packaging and increasing bio-based materials while increasing the level of recyclability and usage of products. Example: Creation of *Snap Pack* technology, used to glue cans together instead of using LDPE six-pack rings.
Adidas https://www.adidas.ca/en/primeblue https://www.adidas.ca/en/primegreen	**By 2040:** Stop the use of virgin PET.	Prime Green and Prime Blue with Parley Ocean Plastic. Use of recycled high-performance material in the creation of consumer goods.
Proctor & Gamble (P&G) https://www.pginvestor.com/esg/environmental/plastic-packaging/default.aspx	**By 2030:** 100% of consumer packaging recyclable/reusable. 50% reduction in virgin plastic n consumer packaging.	Ocean Plastic Bottle with TeeraCycle, to promote awareness of ocean plastic. Fairy dish detergent bottle made from 10% ocean plastic, and 90% recycled plastic. Reduced packaging by 12%/ consumer. Doubled use of recycled resin in packaging.
IKEA https://www.ikea.com/ca/en/this-is-ikea/sustainable-everyday/	**By 2030:** Use of only recycled or renewable based plastic in IKEA products.	Phasing out of all SUPs from furnishings, restaurants, and bistro in 2020. Collaboration with NextWave Plastic to integrate ocean-bound plastic into consumer products. Development of products from PET bottles captured by anglers.
DELL https://www.dell.com/en-ca/dt/corporate/social-impact/advancing-sustainability.htm	**By 2030** For every tonne of product sold, Dell will reuse or recycle an equal amount. 100% of packaging will be made from recycled and renewable sources. > half of Dell's products will be made from recycled, renewable, or reduced carbon emission material.	343.3 million pounds of sustainable material was used in product and packaging. 39.2 million plastic bottles kept out of the ocean since 2019.
Garnier https://www.garnier.ca/en-ca/green-beauty	**By 2030:** All products will be made out of 100% recycled plastic. All plastic products will be recyclable refillable, and/or reusable.	Creation of a plastic waste collection center in India with Plastics for Change. 15,800 tons of plastic saved by use of recycled plastics in the Europe Micellar bottle, and in Europe Fructis Shampoo and Conditioner.

Government-led campaigns can be scientifically motivated to inform the public on the direction of plastic pollution through research. To support Canada’s Zero Plastic Waste Initiative, over $5 million was invested in initiatives. For example, one initiative implemented environmentally friendly and cost-effective alternatives for local food packaging with the Atlantic Coastal Action Program - Cape Breton. Another example is an initiative that assists the Lake St. Martin First Nation community in determining community-specific strategies for increased collection and diversion of plastic waste. Several other countries have also put forth similar initiatives (Table 4-2). Bans and levies can act as deterrents by influencing the market to design alternative materials used for typical plastic products. For example, on July 3, 2021, the European Union banned all SUPs in markets of the EU Member States (European Union, 2021).

4.6.4 Non-Governmental Organization (NGO) Campaigns

Non-governmental Organizations (NGOs) are run independently from governments, they encompass a large number of organizations, and operate in the pursuit of international development through a number of social and political goals. Environmental NGOs (ENGOs) have the ability to influence individuals, as well as governments and institutions (Partelow et al., 2020). Campaigns led by NGOs are crucial for advancing the mitigation of plastic pollution. Such campaigns address plastic pollution at local and global levels. For example, Kehadiran Yayasan Keanekaragaman Hayati Indonesia (KEHATI), an NGO based in Indonesia, has created a local shop offering refillable household products such as shampoo, soaps, and cleaning fluid, to combat increased waste seen in the natural environment (KEHATI Foundation, 2021). There are also several ocean clean-up crews, such as Ocean Conservancy, that lead worldwide cleanups and provide data on the sources and types of debris collected to create awareness and to inform policy makers at the national and international levels. Examples of campaigns led by NGOs are listed in table 4-3.

Table 4-2. Government-led campaigns that have caused positive change concerning plastic pollution.

Country/Region	Name of Campaign	Description of Campaign	Result of Campaign
Europe (European Commission)	Be Ready to Change	Encourage Europeans to use sustainable alternatives instead of SUPs. Video campaign was created to promote new measures from the EU's Circular Economy agenda.	Reached 5.5 million viewers through social media platform (YouTube). Shareability among youth across social media platforms.
New South Wales (Australia)	Return and Earn	Container Deposit Scheme (CDS) to collect beverage containers between 150mL-3L. Eligible containers receive 10c per item. Materials include PET, HDPE, glass, steel, aluminum, and liquid paperboard.	77% of NSW residents have participated. $685 million in refunds paid since start of the CDS. 595,500 tonnes of materials reused/recycled. Mixed plastics =30% of bottles in 2020-2021. Industry participation.
India	Polythene Hatao – Paryavaran Bachao (Remove Poluethylene – Save the Environment)	Collect plastic waste from urban and rural areas and inform the local communities about the detrimental effects.	8,470 tonnes of plastic waste collected on first day. 1,000 participants. Collected waste transported to waste-to-energy plants. Minister Jairam Thankur created and released a guidebook.
Thailand	Everyday Say No to Plastic Bags	Encourage reduction of single use plastic bags. Campaign with over 90 retailers and convenience stores to stop the distribution of plastic bags.	14.3 billion plastic bags were prevented from being littered. Support from more than 90% of the public.
South Africa	PIKUP	Official waste management service of Johannesburg responsible for keeping the city clean. Efforts and campaigns are produced to minimize illegal dumping and littering.	Several YouTube videos show how illegal dumping can affect property value, damage the environment, cause economic decline, and possible solutions. Campaigns orchestrated through print, TV, and radio. ECO Rangers animate series to engage and educate children on plastic pollution.
Jamaica, National Environment and Planning Agency	Plastic Free Jamaica	Use of social media to convey support for the ban on SUPs. Posters provide information, e.g., '5 Reasons to be Foam Free': EPS toxicity, long decomposition rates, breaks down into smaller pieces, non-biodegradable.	Series of informative social media posters across Facebook, Instagram, twitter. 1100 likes and 1200 followers on Facebook. 900+ followers on Instagram. 384 followers on Twitter.

4.6.5 Successful Campaigns

Effective campaigns require a set of foundational factors to successfully inform and influence the target audience. According to the report created by the Stockholm Environment Institute (SEI) and the United Nations Environment Programme (UNEP) “Reducing plastic pollution: campaigns that work” (2021), there are six key campaign elements that influence large groups: (1) customizing the approach to target various audiences, (2) using good social norms to shape behaviour, (3) specifying action with clear direction, (4) catalyzing commitments with a challenge, (5) tapping positive emotions like pride or optimism, and (6) showing it matters, even individual action (Moss, 2021). By employing customizable campaigns that can be adapted to the ongoing and evolving environmental issue of plastic pollution, we can keep communities engaged. It is also crucial to provide feedback through which participants have the ability to monitor progress and reinforce their behaviors. Teaming up with stakeholders produces greater involvement and increased outreach to inform larger masses.

4.6.6 Recommendations for the City of London

Combining the research in this study with a local campaign with the City of London would create a deeper sense of meaning for the community and lead to behavioral change. A campaign could include installation of placards at the most polluted drain locations from this study that pictorially illustrate the main plastic debris items. During periods of high plastic waste generation, for example during summer festivals and other crowd activities, increased waste management resources should be considered. The public could also be encouraged to bring their own reusable cutlery and dishes to outdoor events. Creation of a mobile app would have the ability to motivate the local community to become informed and to take action against plastic pollution. The app would feature a map showing the locations of LittaTraps^{TM} in conjunction with outlined high-pollution areas, including images of commonly littered items. This platform would serve as an educational and news network for the latest updates and trends on plastic pollution in London. It could also include a forum where local citizens could provide feedback and raise concerns. Educational workshops and seminars in collaboration with schools and community centers would also be beneficial to educate citizens on the importance of proper debris disposal. A public art installation could convey the main plastic items to avoid by featuring debris items collected from stormwater sewers.

Table 4-3. Examples of plastic pollution campaigns led by NGOs.

NGO Name	Year	Name of Campaign	Description of Campaign	Result of Campaign
Green Peace	2023	Plastics Street Art in Washington DC	Street posters calling the Biden administration to support a strong Global Plastics Treaty. Examples: 'Joe knows plastic additives can lower semen quality' ' Joe knows chemicals in plastics can cause early puberty' 'Joe knows microplastics have been found in breast milk'	High visibility Pressure on public figures to address posters
Ocean Conservancy	2018	Trash Free Seas	International coastal cleanup engaging citizens in cleaning debris from beaches all around the world. Identification of sources of debris generates annual reports to influence policy.	Since the start of the campaign 17 million volunteers have collected 350 million pounds of trash
World Wildlife Fund (WWF)	2019	Your Plastic Diet	Creates awareness of plastic consumption by humans. Media video showcases the amounts of plastic that individuals consume unknowingly and compares it to everyday items.	Over 37K views. Website contains a global legally binding agreement to end plastic pollution with ca. 2.2 million signatures.
Surfrider Foundation	Est. 1990	Hold On to Your Butt	Increase awareness of cigarette butt litter, eliminate litter on beaches and oceans, hold the tobacco industry accountable. Campaigns in Canada and the U.S.	Since 2017, have recycled over 1 million cigarette butts. Surfrider Pacific Rim created the first cigarette surfboard for educational purposes. Installed cigarette butt receptacles.
Break Free from Plastic		#WeChooseReuse	Promote a future with products that are durable and toxic-free. Calls for the EU to revise the Packaging and Packaging Waste Regulation (PPWR).	100,721 individuals, 165 NGOS, 311 Businesses, and 36 Municipalities have supported this campaign.

5 Conclusions

This study presents a thorough analysis of macroplastic and microplastic pollution found in six urban stormwater drains of London, Ontario, Canada during four seasons. It represents the first project of its kind to investigate particles between 1 and 5 mm in size mobilized by stormwater runoff and trapped in LittaTrap^{TM} devices. The results prove that the 1 mm LittaTrap^{TM} nurdle liner is much more effective at trapping MPs in stormwater drains than the normally used 5 mm liner.

The results of this study also indicate that the quantity and types of plastic debris trapped in stormwater drains are predominantly influenced by human activities, which are partially dependent on seasonal conditions. The winter samples are associated with the lowest number of MaPs and MPs at most sites. This result can be directly related to decreased pedestrian traffic and outdoor public events when the temperatures are colder and the ground has more snow cover which causes immobilization of plastics debris. Although there is a pronounced seasonal signature in overall abundances of plastic debris in each season, this is not directly related to total precipitation amount nor average wind speed over each sampling period. There is no statistical correlation between the two environmental drivers and plastic debris amounts. Although precipitation and wind speed undoubtedly contribute to the transport and deposition of plastic debris in stormwater drains, these factors are complex. Continuous monitoring of debris in each stormwater drain over a multi-year period would be needed to unravel this complexity.

The second crucial driver of plastic debris accumulation in urban London stormwater drains is the location of the drain itself. The sites with the greatest amounts of both MaPs and MPs were Bathurst, Dufferin, and Inner Queens. These locations are all associated with heavy pedestrian traffic according to the City of London collaborators. The Bathurst site is located next to a homeless shelter and Salvation Army, the Dufferin site next to a park in the downtown core where festivals, road races, and other events take place, and Inner Queens in the middle of a parking lot frequented by narcotics-users and buyers. The sites with the lowest amounts of plastic debris were located in a children’s splash pad

(Ivey), on a quiet and high-sloped street (Carfrae), and on the very edge of a parking lot (Outer Queens).

The most common identifiable plastic items found as litter in the six stormwater drains were cigarette butts, wrappers, EPS foam, bottle caps, and films. All items identified were categorized into applications (uses) and the three most common were “smoking-related”, “food and beverage packaging”, and “narcotics”. The sources of MPs were more challenging to determine due to their small size. Assisted by FTIR, rubber particles (e.g. ethylene propylene diene monomer, polybutadiene, and silicone rubber) were identified. Combined with the rubber-like particles identified by microscopy, these results support tire wear as a microplastic source. Other common polymers were alkyds, epoxy resins, urea resins, dodecane, and acrylic resin, which are all associated with construction applications, such as paints and coatings.

From these findings, public awareness and targeted campaigns towards mitigating plastic pollution to the local community, government, and industry must be considered and should not be understated. The examples provided by active campaigns highlight the impact these efforts have in stemming the flow of plastic debris into the environment.

5.1 Future Directions

Additional research could complement the present study through use of a finer mesh size to capture plastic particles. In this study, a 1 mm nurdle liner was used, however a finer LittaTrap^{TM} sediment liner could be used to capture particles >200 µm (Enviropod, n.d). The finer mesh, however, may impede water flow and thus necessitate regular maintenance to prevent overflow and clogging of the sewer catchment basin.

Expanding the geographic area of the study would also be beneficial. By introducing additional LittaTraps^{TM} beyond the city core would elucidate whether urban and suburban areas share similar seasonal patterns in plastic deposition. With additional LittaTrap^{TM} devices, other variables that potentially control plastic deposition could be tested. Some of these could include topographic slope and surface roughness.

Collecting and analyzing water samples from stormwater pipe outlets that discharge into the Thames River and its smaller tributaries would offer valuable assessment of the proportion of plastic waste entering the aquatic environment.

Lastly, collaboration with other researchers studying stormwater drain plastics would supplement this study. Currently, colleagues from the Rochester Institute of Technology and the University of Toronto have LittaTrap^{TM} devices installed. Combining the data from all three cities would provide a more comprehensive understanding of the transfer of plastic debris from terrestrial to aquatic settings.

References

Adidas. (n.d.). PrimeGreen. https://www.adidas.ca/en/primegreen [accessed 20 September 2023].

Adidas. (n.d.). PrimeBlue. https://www.adidas.ca/en/primeblue [accessed 20 September 2023].

Afrin, S., Rahman, Md. M., Hossain, Md. N., Uddin, Md. K., & Malafaia, G. (2022). Are there plastic particles in my sugar? A pioneering study on the characterization of microplastics in commercial sugars and risk assessment. Science of The Total Environment, 837, 155849. https://doi.org/10.1016/j.scitotenv.2022.155849

Ahuja, Aastha. (2018, May 29). Polythene Hatao, Paryavaran Bachao: Himachal Pradesh Chief Minister Jairam Thakur Launches A Campaign Against Plastic Bags. Swachhindia. https://swachhindia.ndtv.com/world-environment-day-polythene-hatao-paryavaran-bachao-campaign-launched-in-himachal-pradesh-20498/ [accessed 21 September 2023]

Ambrose, R. F., & Winfrey, B. K. (2015). Comparison of stormwater biofiltration systems in Southeast Australia and Southern California. WIREs Water, 2(2), 131–146. https://doi.org/10.1002/wat2.1064

Andrady, A. L. (2011). Microplastics in the marine environment. Marine Pollution Bulletin, 62(8), 1596–1605. https://doi.org/10.1016/j.marpolbul.2011.05.030

Andrady, A. L., & Neal, M. A. (2009). Applications and societal benefits of plastics. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 1977–1984. https://doi.org/10.1098/rstb.2008.0304

Arthur, C., Baker, J., & Bamford, H. (Eds). (2009). Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris. Sept 9-11, 2008. NOAA Technical Memorandum NOS-OR&R30. https://repository.library.noaa.gov/view/noaa/2509 [accessed 12 August 2023].

Auburn, Luke. (2023, April 7). RIT and Seneca Park Zoo Society to host Great Lakes Plastic Cleanup event at the Port of Rochester. RIT. https://www.rit.edu/news/rit-and-seneca-park-zoo-society-host-great-lakes-plastic-cleanup-event-port-rochester [accessed 19 September 2023].

Auta, H. S., Emenike, C. U., & Fauziah, S. H. (2017). Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. Environment International, 102, 165–176. https://doi.org/10.1016/j.envint.2017.02.013

Azevedo-Santos, V. M., Brito, M. F. G., Manoel, P. S., Perroca, J. F., Rodrigues-Filho, J. L., Paschoal, L. R. P., Gonçalves, G. R. L., Wolf, M. R., Blettler, M. C. M., Andrade, M. C., Nobile, A. B., Lima, F. P., Ruocco, A. M. C., Silva, C. V., Perbiche-Neves, G., Portinho, J. L., Giarrizzo, T., Arcifa, M. S., & Pelicice, F. M. (2021). Plastic pollution: A focus on freshwater biodiversity. Ambio, 50(7), 1313–1324. https://doi.org/10.1007/s13280-020-01496-5

Baekeland, L. H. (1909). The Synthesis, Constitution, and Uses of Bakelite. Journal of Industrial & Engineering Chemistry, 1(3), 149–161. https://doi.org/10.1021/ie50003a004

Baensch-Baltruschat, B., Kocher, B., Stock, F., & Reifferscheid, G. (2020). Tyre and road wear particles (TRQP)- A review of generation, properties, emissions, human health risk, ecotoxicity, and fate in the environment. *Science of the Total Environment*, 733, 137823. https://doi:10.1016/j.scitotenv.2020.137823

Bailey, I. (2022). Media coverage, attention cycles and the governance of plastics pollution. Environmental Policy and Governance, 32(5), 377–389. https://doi.org/10.1002/eet.1977

Baker, N., Sullivan, D., Selbig, W., Haefner, R., Lampe, D., Bayless, R., & McHale, M. (2022). Green Infrastructure in the Great Lakes—Assessment of Performance, Barriers, and Unintended Consequences. U.S Geological Survey Circular 1469. https://doi.org/https://doi.org/10.3133/cir1496

Ballent, A., Corcoran, P. L., Madden, O., Helm, P. A., & Longstaffe, F. J. (2016). Sources and sinks of microplastics in Canadian Lake Ontario nearshore, tributary and beach sediments. Marine Pollution Bulletin, 110(1), 383–395. https://doi.org/10.1016/j.marpolbul.2016.06.037

Banaee, M., Soltanian, S., Sureda, A., Gholamhosseini, A., Haghi, B. N., Akhlaghi, M., & Derikvandy, A. (2019). Evaluation of single and combined effects of cadmium and micro-plastic particles on biochemical and immunological parameters of common carp (Cyprinus carpio). Chemosphere, 236, 124335. https://doi.org/10.1016/j.chemosphere.2019.07.066

Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 1985–1998. https://doi.org/10.1098/rstb.2008.0205

Basaran, B., Özçifçi, Z., Akcay, H. T., & Aytan, Ü. (2023). Microplastics in branded milk: Dietary exposure and risk assessment. Journal of Food Composition and Analysis, 123, 105611. https://doi.org/10.1016/j.jfca.2023.105611

Bauer-Civiello, A. M. (2019). From people to reefs: marine debris and plastic pollution in North Queensland. [Doctoral dissertation, James Cook University].

Belzagui, F., Buscio, V., Gutiérrez-Bouzán, C., & Vilaseca, M. (2021). Cigarette butts as a microfiber source with a microplastic level of concern. Science of The Total Environment, 762, 144165. https://doi.org/10.1016/j.scitotenv.2020.144165

Besseling, E., Redondo-Hasselerharm, P., Foekema, E. M., & Koelmans, A. A. (2019). Quantifying ecological risks of aquatic micro- and nanoplastic. Critical Reviews in Environmental Science and Technology, 49(1), 32–80. https://doi.org/10.1080/10643389.2018.1531688

Bhattacharya, P. (2016). A review on the impacts of microplastic beads used in cosmetics. Acta Biomed. Sci, 3, 47-52.

Blair, R. M., Waldron, S., Phoenix, V., & Gauchotte-Lindsay, C. (2017). Micro- and Nanoplastic Pollution of Freshwater and Wastewater Treatment Systems. Springer Science Reviews, 5(1–2), 19–30. https://doi.org/10.1007/s40362-017-0044-7

Blettler, M. C. M., & Mitchell, C. (2021). Dangerous traps: Macroplastic encounters affecting freshwater and terrestrial wildlife. Science of The Total Environment, 798, 149317. https://doi.org/10.1016/j.scitotenv.2021.149317

Borawska, A. (2017). The Role of Public Awareness Campaigns in Sustainable Development. Economic and Environmental Studies, 17(44), 865–877. https://doi.org/10.25167/ees.2017.44.14

Boucher, J., & Friot, D. (2018). Primary microplastics in the oceans: A global evaluation of sources. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2017.01.en

Break Free from Plastic. (n.d.). Over 100,000 EU citizens, businesses, NGOs and cities are calling for REUSE. #wechoosereuse. https://wechoosereuse.org/ [accessed 19 September 2023].

British Plastics Federation. (n.d.). Thermoplastics. https://www.bpf.co.uk/plastipedia/polymers/polymer-thermoplastics.aspx [accessed 15 May 2023].

Brookson, C. B., de Solla, S. R., Fernie, K. J., Cepeda, M., & Rochman, C. M. (2019). Microplastics in the diet of nestling double-crested cormorants (Phalacrocorax auritus), an obligate piscivore in a freshwater ecosystem. Canadian Journal of Fisheries and Aquatic Sciences, 76(11), 2156–2163. https://doi.org/10.1139/cjfas-2018-0388

Browne, M. A., Galloway, T. S., & Thompson, R. C. (2010). Spatial Patterns of Plastic Debris along Estuarine Shorelines. Environmental Science & Technology, 44(9), 3404–3409. https://doi.org/https://doi.org/10.1021/es903784e

Callister, W. D., & Rethwisch, D. G. (2018). Materials science and engineering: An introduction (10th ed.). Hoboken, NJ: Wiley.

Canada Gazette. (2016). Order Adding a Toxic Substance to Schedule 1 to the Canadian Environmental Protection Act, 1999. Government of Canada. https://gazette.gc.ca/rp-pr/p2/2016/2016-06-29/html/sor-dors150-eng.html [accessed 19 September 2023].

Canada Gazette. (2021). Canada Gazette, Part I, Volume 155, Number 52: Single Use Plastics Prohibition Regulations. Government of Canada. https://www.gazette.gc.ca/rp-pr/p1/2021/2021-12-25/html/reg2-eng.html. [accessed 19 September 2023].

Cardarelli, F. (2018). Polymers and Elastomers. In Materials Handbook (pp. 1013–1092). Springer International Publishing. https://doi.org/10.1007/978-3-319-38925-7_11

Carlsberg Group. (n.d.). Zero Packaging Waste. https://www.carlsberggroup.com/sustainability/our-esg-programme/zero-packaging-waste/ [accessed 18 September 2023].

Carpenter, E. J., & Smith, K. L. (1972). Plastics on the Sargasso Sea Surface. Science, 175(4027), 1240–1241. https://doi.org/10.1126/science.175.4027.1240

Chae, Y., & An, Y.-J. (2017). Effects of micro- and nanoplastics on aquatic ecosystems: Current research trends and perspectives. Marine Pollution Bulletin, 124(2), 624–632. https://doi.org/10.1016/j.marpolbul.2017.01.070

Chanda, M., & Roy, S. K. (2006). Plastics Technology Handbook. CRC Press. https://doi.org/10.1201/9781420006360

Chen, C.-L., Kuo, P.-H., Lee, T.-C., & Liu, C.-H. (2018). Snow lines on shorelines: Solving Styrofoam buoy marine debris from oyster culture in Taiwan. Ocean & Coastal Management, 165, 346–355. https://doi.org/10.1016/j.ocecoaman.2018.09.005

Chen, Q., Zhao, H., Liu, Y., Jin, L., & Peng, R. (2023). Factors Affecting the Adsorption of Heavy Metals by Microplastics and Their Toxic Effects on Fish. Toxics, 11(6), 490. https://doi.org/10.3390/toxics11060490

Chitaka, T. Y., & von Blottnitz, H. (2019). Accumulation and characteristics of plastic debris along five beaches in Cape Town. Marine Pollution Bulletin, 138, 451–457. https://doi.org/10.1016/j.marpolbul.2018.11.065

Cohen, J. H., Internicola, A. M., Mason, R. A., & Kukulka, T. (2019). Observations and Simulations of Microplastic Debris in a Tide, Wind, and Freshwater-Driven Estuarine Environment: the Delaware Bay. Environmental Science & Technology, 53(24), 14204–14211. https://doi.org/10.1021/acs.est.9b04814

Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin, 62(12), 2588–2597. https://doi.org/10.1016/j.marpolbul.2011.09.025

Corcoran, P. L. (2022). Degradation of Microplastics in the Environment. In Handbook of Microplastics in the Environment (pp. 531–542). Springer International Publishing. https://doi.org/10.1007/978-3-030-39041-9_10

Corcoran, P. L., Belontz, S. L., Ryan, K., & Walzak, M. J. (2020). Factors Controlling the Distribution of Microplastic Particles in Benthic Sediment of the Thames River, Canada. Environmental Science & Technology, 54(2), 818–825. https://doi.org/10.1021/acs.est.9b04896

Corcoran, P. L., Jazvac, K., & Ballent, A. (2018). Plastics and the Anthropocene. In Encyclopedia of the Anthropocene (Vols. 1–5, pp. 163–170). Elsevier Inc. https://doi.org/10.1016/B978-0-12-809665-9.10000-X

Corcoran, P. L., Norris, T., Ceccanese, T., Walzak, M. J., Helm, P. A., & Marvin, C. H. (2015). Hidden plastics of Lake Ontario, Canada and their potential preservation in the sediment record. Environmental Pollution, 204, 17–25. https://doi.org/10.1016/j.envpol.2015.04.009

Cox, K. D., Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F., & Dudas, S. E. (2019). Human Consumption of Microplastics. Environmental Science & Technology, 53(12), 7068–7074. https://doi.org/10.1021/acs.est.9b01517

Coyle, R., Hardiman, G., & Driscoll, K. O. (2020a). Microplastics in the marine environment: A review of their sources, distribution processes, uptake and exchange in ecosystems. Case Studies in Chemical and Environmental Engineering, 2, 100010. https://doi.org/10.1016/j.cscee.2020.100010

Coyle, R., Hardiman, G., & Driscoll, K. O. (2020b). Microplastics in the marine environment: A review of their sources, distribution processes, uptake and exchange in ecosystems. Case Studies in Chemical and Environmental Engineering, 2, 100010. https://doi.org/10.1016/j.cscee.2020.100010

da Costa, J. P., Santos, P. S. M., Duarte, A. C., & Rocha-Santos, T. (2016). (Nano)plastics in the environment – Sources, fates and effects. Science of The Total Environment, 566–567, 15–26. https://doi.org/10.1016/j.scitotenv.2016.05.041

De Falco, F., Cocca, M., Avella, M., & Thompson, R. C. (2020). Microfiber Release to Water, Via Laundering, and to Air, via Everyday Use: A Comparison between Polyester Clothing with Differing Textile Parameters. Environmental Science & Technology, 54(6), 3288–3296. https://doi.org/10.1021/acs.est.9b06892

de Souza, F. M., Desai, Y., & Gupta, R. K. (2023). Introduction to Polymeric Foams (pp. 1–23). https://doi.org/10.1021/bk-2023-1439.ch001

DELL Technologies. (2022). FY23 Environmental, Social and Governance Report. DELL Technologies. www.delltechnologies.com/asset/en-ca/solutions/business-solutions/briefs-summaries/delltechnologies-fy23-esg-report.pdf [accessed 19 September 2023].

Department of Justice Canada. (2017). Microbeads in Toiletries Regulations [SOR/2017-111]. https://laws-lois.justice.gc.ca/eng/regulations/SOR-2017-111/page-1.html [accessed 21 September 2023].

Dris, R., Gasperi, J., Saad, M., Mirande, C., & Tassin, B. (2016). Synthetic fibers in atmospheric fallout: A source of microplastics in the environment? Marine Pollution Bulletin, 104(1–2), 290–293. https://doi.org/10.1016/j.marpolbul.2016.01.006

ECCC & HC (Environment and Climate Change Canada & Health Canada). (2020) Science assessment of plastic pollution. http://publications.gc.ca/pub?id=9.890913&sl=0

ECCC. (2020). Canada One-Step Closer to Zero Plastic Waste by 2023. https://www.canada.ca/en/environment-climate-change/news/2020/10/canada-one-step-closer-to-zero-plastic-waste-by-2030.html [accessed 19 September 2023].

ECCC. (2022). Single-use Plastics Prohibtion Regulations – Guidance for selecting alternatives. Government of Canada. https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/reduce-plastic-waste/single-use-plastic-guidance.html [accessed 19 September 2023].

Enviropod. (n.d.). *Keeping Canada's waterways free from pollution.* https://www.enviropod.com/en-ca [accessed 8 March 2023].

Erni-Cassola, G., Zadjelovic, V., Gibson, M. I., & Christie-Oleza, J. A. (2019). Distribution of plastic polymer types in the marine environment; A meta-analysis. Journal of Hazardous Materials, 369, 691–698. https://doi.org/10.1016/j.jhazmat.2019.02.067

Eslami, S., Kabir, G., & Ng, K. T. W. (2023). Waste Generation Modeling Using System Dynamics with Seasonal and Educational Considerations. Sustainability, 15(13), 9995. https://doi.org/10.3390/su15139995

European Commission, Directorate-General for Environment. (2021). Turning the tide on single-use plastics. Publications Office of the European Union. https://data.europa.eu/doi/10.2779/800074. [accessed 17 September 2023].

European Commission. (2018, June 4). Be Ready to Change [Video]. Youtube. https://www.youtube.com/watch?v=3aiDlHhYrmg [accessed 17 September 2023].

Evangeliou, N., Grythe, H., Klimont, Z., Heyes, C., Eckhardt, S., Lopez-Aparicio, S., & Stohl, A. (2020). Atmospheric transport is a major pathway of microplastics to remote regions. Nature Communications, 11(1), 3381. https://doi.org/10.1038/s41467-020-17201-9

Fang, C., Zheng, R., Chen, H., Hong, F., Lin, L., Lin, H., Guo, H., Bailey, C., Segner, H., Mu, J., & Bo, J. (2019). Comparison of microplastic contamination in fish and bivalves from two major cities in Fujian province, China and the implications for human health. Aquaculture, 512, 734322. https://doi.org/10.1016/j.aquaculture.2019.734322

Finnegan, A. M. D., Süsserott, R., Gabbott, S. E., & Gouramanis, C. (2022). Man-made natural and regenerated cellulosic fibres greatly outnumber microplastic fibres in the atmosphere. Environmental Pollution, 310, 119808. https://doi.org/10.1016/j.envpol.2022.119808

Flory, J. F., Hearle, J., McKenna, H., & Parsey, M. (2015). About 75 years of synthetic fiber rope history. OCEANS 2015 - MTS/IEEE Washington, 1–13. https://doi.org/10.23919/OCEANS.2015.7404500

Frydkjær, C. K., Iversen, N., & Roslev, P. (2017). Ingestion and Egestion of Microplastics by the Cladoceran Daphnia magna: Effects of Regular and Irregular Shaped Plastic and Sorbed Phenanthrene. Bulletin of Environmental Contamination and Toxicology, 99(6), 655–661. https://doi.org/10.1007/s00128-017-2186-3

Gad, S. E. (2014). Polymers. Encyclopedia of Toxicology: Third Edition, 1045–1050. https://doi.org/10.1016/B978-0-12-386454-3.00912-X

Gambino, I., Bagordo, F., Grassi, T., Panico, A., & De Donno, A. (2022). Occurrence of Microplastics in Tap and Bottled Water: Current Knowledge. International Journal of Environmental Research and Public Health, 19(9), 5283. https://doi.org/10.3390/ijerph19095283

Garnier Scientific & Sustainability Team. (2022). SUSTAINABILITY PROGRESS REPORT 2022. Garnier. https://www.garnier.ca/en-ca/green-beauty

Gaylarde, C.C., Baptista Neto, J.A., & Monteiro da Fonseca, E. (2021). Paint fragments as polluting microplastics: A brief review. *Marine Pollution Bulletin, 162*. https://doi.org/10.1016/j.marpolbul.2020.111847.

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7). https://doi.org/10.1126/sciadv.1700782

Giacovelli, C. (2018). Single-use plastics, a roadmap for sustainability. UN Environment: Technology for Environment. Retrieved October 19, 2023, from https://stg-wedocs.unep.org/handle/20.500.11822/25496 [accessed 14 September 2023].

Giechaskiel, B., & Clairotte, M. (2021). Fourier Transform Infrared (FTIR) Spectroscopy for Measurements of Vehicle Exhaust Emissions: A Review. Applied Sciences, 11(16), 7416. https://doi.org/10.3390/app11167416

Godwin, A. D. (2017). Plasticizers. In Applied Plastics Engineering Handbook (pp. 533–553). Elsevier. https://doi.org/10.1016/B978-0-323-39040-8.00025-0

Gouin, T., Avalos, J., Brunning, I., Brzuska, K., de, J., Kaumanns, J., Konong, T., Meyberg, M., Rettinger, K., Schlatter, H., Thomas, J., van, R. & Wolf, T.(2015). Use of micro-plastic beads in cosmetic products in Europe and their estimated emissions to the North Sea environment. SOFW-Journal. 141. 1-33.

Grbić, J., Helm, P., Athey, S., & Rochman, C. M. (2020). Microplastics entering northwestern Lake Ontario are diverse and linked to urban sources. Water Research, 174, 115623. https://doi.org/10.1016/j.watres.2020.115623

Green Peace. (2023, October 25). Plastics Street Art in Washington DC. https://media.greenpeace.org/Detail/27MZIFJF64NUH [accessed 12 September 2023].

Grgić, I., Cetinić, K. A., Karačić, Z., Previšić, A., & Rožman, M. (2023). Fate and effects of microplastics in combination with pharmaceuticals and endocrine disruptors in freshwaters: Insights from a microcosm experiment. Science of The Total Environment, 859, 160387. https://doi.org/10.1016/j.scitotenv.2022.160387

Groh, K. J., Backhaus, T., Carney-Almroth, B., Geueke, B., Inostroza, P. A., Lennquist, A., Leslie, H. A., Maffini, M., Slunge, D., Trasande, L., Warhurst, A. M., & Muncke, J. (2019). Overview of known plastic packaging-associated chemicals and their hazards.

Science of The Total Environment, 651, 3253–3268. https://doi.org/10.1016/j.scitotenv.2018.10.015

Gündoğdu, S. (2018). Contamination of table salts from Turkey with microplastics. Food Additives & Contaminants: Part A, 35(5), 1006–1014. https://doi.org/10.1080/19440049.2018.1447694

Hartmann, N. B., Hüffer, T., Thompson, R. C., Hassellöv, M., Verschoor, A., Daugaard, A. E., Rist, S., Karlsson, T., Brennholt, N., Cole, M., Herrling, M. P., Hess, M. C., Ivleva, N. P., Lusher, A. L., & Wagner, M. (2019). Are We Speaking the Same Language? Recommendations for a Definition and Categorization Framework for Plastic Debris. Environmental Science & Technology, 53(3), 1039–1047. https://doi.org/10.1021/acs.est.8b05297

Hernandez, L. M., Xu, E. G., Larsson, H. C. E., Tahara, R., Maisuria, V. B., & Tufenkji, N. (2019). Plastic Teabags Release Billions of Microparticles and Nanoparticles into Tea. Environmental Science & Technology, 53(21), 12300–12310. https://doi.org/10.1021/acs.est.9b02540

Herrera, A., Acosta-Dacal, A., Pérez Luzardo, O., Martínez, I., Rapp, J., Reinold, S., Montesdeoca-Esponda, S., Montero, D., & Gómez, M. (2022). Bioaccumulation of additives and chemical contaminants from environmental microplastics in European seabass (Dicentrarchus labrax). Science of The Total Environment, 822, 153396. https://doi.org/10.1016/j.scitotenv.2022.153396

Hidayaturrahman, H., & Lee, T.-G. (2019). A study on characteristics of microplastic in wastewater of South Korea: Identification, quantification, and fate of microplastics during treatment process. Marine Pollution Bulletin, 146, 696–702. https://doi.org/10.1016/j.marpolbul.2019.06.071

Hitchcock, J. N. (2022). Microplastics can alter phytoplankton community composition. Science of The Total Environment, 819, 153074. https://doi.org/10.1016/j.scitotenv.2022.153074

Horton, A. A., & Dixon, S. J. (2018). Microplastics: An introduction to environmental transport processes. WIREs Water, 5(2). https://doi.org/10.1002/wat2.1268

Huang, Y., Liu, Q., Jia, W., Yan, C., & Wang, J. (2020). Agricultural plastic mulching as a source of microplastics in the terrestrial environment. Environmental Pollution, 260, 114096. https://doi.org/10.1016/j.envpol.2020.114096

Hunt, C. F., Lin, W. H., & Voulvoulis, N. (2020). Evaluating alternatives to plastic microbeads in cosmetics. Nature Sustainability, 4(4), 366–372. https://doi.org/10.1038/s41893-020-00651-w

Hurley, R., Horton, A., Lusher, A., & Nizzetto, L. (2020). Plastic waste in the terrestrial environment. In Plastic Waste and Recycling (pp. 163–193). Elsevier. https://doi.org/10.1016/B978-0-12-817880-5.00007-4

IKEA. (n.d.). A sustainable everyday. https://www.ikea.com/ca/en/this-is-ikea/sustainable-everyday/ [accessed 20 September 2023].

Issac, M. N., & Kandasubramanian, B. (2021). Effect of microplastics in water and aquatic systems. Environmental Science and Pollution Research, 28(16), 19544–19562. https://doi.org/10.1007/s11356-021-13184-2

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768–771. https://doi.org/10.1126/science.1260352

Joburg. (n.d.). Clean-Up Campaign. Pikitup. https://www.pikitup.co.za/?page_id=5534 [accessed 16 September 2023].

KEHATI foundation. (2021). Addressing Plastic Waste, KEHATI Foundation Establishes a Cura Store in Harapan Island. https://kehati.or.id/en/addressing-plastic-waste-kehati-foundation-establishes-a-cura-store-in-harapan-island/ [accessed 16 September 2023].

Kole, P. J., Löhr, A. J., Van Belleghem, F., & Ragas, A. (2017). Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment. International Journal of

Environmental Research and Public Health, 14(10), 1265. https://doi.org/10.3390/ijerph14101265

Kosore, C. M., Ojwang, L., Maghanga, J., Kamau, J., Shilla, D., Everaert, G., Khan, F. R., & Shashoua, Y. (2022). Microplastics in Kenya’s marine nearshore surface waters: Current status. Marine Pollution Bulletin, 179, 113710. https://doi.org/10.1016/j.marpolbul.2022.113710

Kühne, F., Biedermann, M., Eicher, A., Felder, F., Sander, S., Schmidt, R., Lehmann, S., McCombie, G., Merkel, S., Kappenstein, O., & Luch, A. (2021). Characterisation of Elastomers as Food Contact Materials–Part 1: Quantification of Extractable Compounds, Swelling of Elastomers in Food Simulants and Release of Elements. Molecules, 26(2), 509. https://doi.org/10.3390/molecules26020509

Kumar, R., Manna, C., Padha, S., Verma, A., Sharma, P., Dhar, A., Ghosh, A., & Bhattacharya, P. (2022). Micro(nano)plastics pollution and human health: How plastics can induce carcinogenesis to humans? Chemosphere, 298, 134267. https://doi.org/10.1016/j.chemosphere.2022.134267

Kumar, R., Verma, A., Shome, A., Sinha, R., Sinha, S., Jha, P. K., Kumar, R., Kumar, P., Shubham, Das, S., Sharma, P., & Vara Prasad, P. V. (2021). Impacts of Plastic Pollution on Ecosystem Services, Sustainable Development Goals, and Need to Focus on Circular Economy and Policy Interventions. Sustainability, 13(17), 9963. https://doi.org/10.3390/su13179963

Kutralam-Muniasamy, G., Shruti, V. C., Pérez-Guevara, F., & Roy, P. D. (2023). Microplastic diagnostics in humans: “The 3Ps” Progress, problems, and prospects. Science of The Total Environment, 856, 159164. https://doi.org/10.1016/j.scitotenv.2022.159164

Lahens, L., Strady, E., Kieu-Le, T.-C., Dris, R., Boukerma, K., Rinnert, E., Gasperi, J., & Tassin, B. (2018). Macroplastic and microplastic contamination assessment of a tropical river (Saigon River, Vietnam) transversed by a developing megacity. Environmental Pollution, 236, 661–671. https://doi.org/10.1016/j.envpol.2018.02.005

Landon-Lane, M. (2018). Corporate social responsibility in marine plastic debris governance. Marine Pollution Bulletin, 127, 310–319. https://doi.org/10.1016/j.marpolbul.2017.11.054

Lau, S.-L., Khan, E., & Stenstrom, M. K. (2001). Catch basin inserts to reduce pollution from stormwater. Water Science and Technology, 44(7), 23–34. https://doi.org/10.2166/wst.2001.0381

Lau, W. W. Y., Shiran, Y., Bailey, R. M., Cook, E., Stuchtey, M. R., Koskella, J., Velis, C. A., Godfrey, L., Boucher, J., Murphy, M. B., Thompson, R. C., Jankowska, E., Castillo Castillo, A., Pilditch, T. D., Dixon, B., Koerselman, L., Kosior, E., Favoino, E., Gutberlet, J., … Palardy, J. E. (2020). Evaluating scenarios toward zero plastic pollution. Science, 369(6510), 1455–1461. https://doi.org/10.1126/science.aba9475

Le, T. T. (2022). How do corporate social responsibility and green innovation transform corporate green strategy into sustainable firm performance? Journal of Cleaner Production, 362, 132228. https://doi.org/10.1016/j.jclepro.2022.132228

Lebreton, L. C. M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world’s oceans. Nature Communications, 8(1), 15611. https://doi.org/10.1038/ncomms15611

Leslie, H. A., Brandsma, S. H., van Velzen, M. J. M., & Vethaak, A. D. (2017). Microplastics en route: Field measurements in the Dutch river delta and Amsterdam canals, wastewater treatment plants, North Sea sediments and biota. Environment International, 101, 133–142. https://doi.org/10.1016/j.envint.2017.01.018

Li, J., Green, C., Reynolds, A., Shi, H., & Rotchell, J. M. (2018). Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. Environmental Pollution, 241, 35–44. https://doi.org/10.1016/j.envpol.2018.05.038

Li, J., Liu, H., & Paul Chen, J. (2018). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. Water Research, 137, 362–374. https://doi.org/10.1016/j.watres.2017.12.056

Li, X., Xu, Q., Cheng, Y., Chen, C., Shen, C., Zhang, C., Zheng, D., & Zhang, D. (2022). Effect of microplastics on microbial dechlorination of a polychlorinated biphenyl mixture (Aroclor 1260). Science of The Total Environment, 831, 154904. https://doi.org/10.1016/j.scitotenv.2022.154904

Liu, G., Zhu, Z., Yang, Y., Sun, Y., Yu, F., & Ma, J. (2019). Sorption behavior and mechanism of hydrophilic organic chemicals to virgin and aged microplastics in freshwater and seawater. Environmental Pollution, 246, 26–33. https://doi.org/10.1016/j.envpol.2018.11.100

London Weather Stats. (2023). *Temperature - Weekly data.* https://london.weatherstats.ca/metrics/temperature.html [accessed 1 May 2023].

London Weather Stats. (2023). *Total Precipitation - Weekly data.* https://london.weatherstats.ca/metrics/precipitation.html [accessed 1 May 2023].

London Weather Stats. (2023). *Wind Speed - Monthly data.* https://london.weatherstats.ca/metrics/wind_speed.html [accessed 1 May 2023].

Mariani, F., Di Lernia, D., Venditti, I., Pelella, E., Muzzi, M., Di Giulio, A., & Ceschin, S. (2023). Trophic transfer of microplastics from producer (Lemna minuta) to primary consumer (Cataclysta lemnata) in a freshwater food chain. Science of The Total Environment, 891, 164459. https://doi.org/10.1016/j.scitotenv.2023.164459

Marturano, V., Cerruti, P., & Ambrogi, V. (2017). Polymer additives. Physical Sciences Reviews, 2(6). https://doi.org/10.1515/psr-2016-0130

Meijer, L. J. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Science Advances, 7(18). https://doi.org/10.1126/sciadv.aaz5803

Mishra, S., Rath, C. charan, & Das, A. P. (2019). Marine microfiber pollution: A review on present status and future challenges. Marine Pollution Bulletin, 140, 188–197. https://doi.org/10.1016/j.marpolbul.2019.01.039

Moss, E. (2021). Reducing Plastic Pollution: Campaigns That Work. https://www.sei.org/wp-content/uploads/2021/02/210216-caldwell-sle-plastics-report-with-annex-210211.pdf [accessed 14 September 2023].

Muller, B. (2011). Colorants for Thermoplastic Polymers. In Applied Plastics Engineering Handbook (pp. 435–440). Elsevier. https://doi.org/10.1016/B978-1-4377-3514-7.10043-1

Napper, I. E., & Thompson, R. C. (2016). Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. Marine Pollution Bulletin, 112(1–2), 39–45. https://doi.org/10.1016/j.marpolbul.2016.09.025

Naqash, N., Prakash, S., Kapoor, D., & Singh, R. (2020). Interaction of freshwater microplastics with biota and heavy metals: a review. Environmental Chemistry Letters, 18(6), 1813–1824. https://doi.org/10.1007/s10311-020-01044-3

National Environment and Planning Agency. (2018, January 11). 5 Reasons to be Foam Free. [Image attached][Image Post]. Facebook. https://www.facebook.com/photo/?fbid=420430875504278&set=pcb.420431062170926 [accessed 17 September 2023].

NSW EPA. (2022). Return and Earn: Annual Statutory Report 2021-22. NSW EPA. https://returnandearn.org.au/wp-content/uploads/2018/05/2021-22-NSW-CDS-Annual-Report_FINAL.pdf [accessed 18 September 2023].

Ó Briain, O., Marques Mendes, A. R., McCarron, S., Healy, M. G., & Morrison, L. (2020). The role of wet wipes and sanitary towels as a source of white microplastic fibres in the marine environment. Water Research, 182, 116021. https://doi.org/10.1016/j.watres.2020.116021

O’Brien, S., Rauert, C., Ribeiro, F., Okoffo, E. D., Burrows, S. D., O’Brien, J. W., Wang, X., Wright, S. L., & Thomas, K. V. (2023). There’s something in the air: A review of sources, prevalence and behaviour of microplastics in the atmosphere. Science of The Total Environment, 874, 162193. https://doi.org/10.1016/j.scitotenv.2023.162193

O'Rourke, K., Wurzer, C., Murray, J., Doyle, A., Doyle, K., Griffin, C., Christensen, B., Brádaigh, C. M. Ó., & Ray, D. (2022). Diverted from Landfill: Reuse of Single-Use Plastic Packaging Waste. Polymers, 14(24), 5485. https://doi.org/10.3390/polym14245485

Ocean Conservancy. (2023). #SeatheChange. https://oceanconservancy.org/wp-content/uploads/2021/09/Annual-Report_FINAL_Digital.pdf [accessed 19 September 2023].

Ocean Conservatory. (n.d.). Fighting for Trash Free Seas – Ending the flow of trash at the source. https://oceanconservancy.org/trash-free-seas/ [accessed 19 September 2023].

Ocean Conservatory. (n.d.). INTERNATIONAL TRASH TRAP NETWORK DETAILED WASTE CHARACTERIZATION PROTOCOL. https://oceanconservancy.org/wp-content/uploads/2022/11/Detailed-Waste-Characterization-Protocol_2022_New14.pdf [accessed 19 September 2023].

Ocean Wise. (2023). Cigarette butts, plastic and food wrappers remain top litter items on Canadian shorelines. https://ocean.org/blog/cigarette-butts-plastic-and-food-wrappers-remain-top-litter-items-on-canadian-shorelines/ [accessed 19 September 2023].

OECD. (2022). Global Plastics Outlook : economic drivers, environmental impacts and policy options. OECD. https://doi.org/10.1787/de747aef-en [accessed 19 September 2023].

Oguge, N., Oremo, F., & Adhiambo, S. (2021). Investigating the Knowledge and Attitudes towards Plastic Pollution among the Youth in Nairobi, Kenya. Social Sciences, 10(11), 408. https://doi.org/10.3390/socsci10110408

Oliveri Conti, G., Ferrante, M., Banni, M., Favara, C., Nicolosi, I., Cristaldi, A., Fiore, M., & Zuccarello, P. (2020). Micro- and nano-plastics in edible fruit and vegetables. The first diet risks assessment for the general population. Environmental Research, 187, 109677. https://doi.org/10.1016/j.envres.2020.109677

Pan, C.-G., Mintenig, S. M., Redondo-Hasselerharm, P. E., Neijenhuis, P. H. M. W., Yu, K.-F., Wang, Y.-H., & Koelmans, A. A. (2021). Automated μFTIR Imaging Demonstrates

Taxon-Specific and Selective Uptake of Microplastic by Freshwater Invertebrates. Environmental Science & Technology, 55(14), 9916–9925. https://doi.org/10.1021/acs.est.1c03119

Pan, T., Liao, H., Yang, F., Sun, F., Guo, Y., Yang, H., Feng, D., Zhou, X., & Wang, Q. (2023). Review of microplastics in lakes: sources, distribution characteristics, and environmental effects. Carbon Research, 2(1), 25. https://doi.org/10.1007/s44246-023-00057-1

Parkes, A. (1866). On the properties of Parkesine, and its application to the arts and manufactures. Journal of the Franklin Institute, 81(4), 264–271. https://doi.org/10.1016/0016-0032(66)90104-9

Partelow, S., Winkler, K. J., & Thaler, G. M. (2020). Environmental non-governmental organizations and global environmental discourse. PLOS ONE, 15(5), e0232945. https://doi.org/10.1371/journal.pone.0232945

Patel, A. B., Shaikh, S., Jain, K. R., Desai, C., & Madamwar, D. (2020). Polycyclic Aromatic Hydrocarbons: Sources, Toxicity, and Remediation Approaches. Frontiers in Microbiology, 11. https://doi.org/10.3389/fmicb.2020.562813

Pattaya Mail. (2023, February 20). ’Every Day Say No to Plastic Bags’ campaign targets 100% achievement by 2027. Pattaya Mail. https://www.pattayamail.com/chiangmaimail/every-day-say-no-to-plastic-bags-campaign-targets-100-achievement-by-2027-424729 [accessed 17 September 2023].

Peters, E. N. (2015). Thermoplastics, thermosets, and elastomers—Descriptions and properties. Mechanical Engineers' Handbook, Volume 1: Materials and Engineering Mechanics, 1, (pp. 353). John Wiley & Sons.

Pfaff, G. (2022). The world of inorganic pigments. ChemTexts, 8(3), 15. https://doi.org/10.1007/s40828-022-00166-1

Plastic Free School. (2023). How To Make Your School Plastic Free. Surfrider. https://plasticfreeschools.ca/how-to-make-your-school-plastic-free/ [accessed 19 September 2023].

Plastics Europe. (2022). Plastics- the Facts 2022. https://plasticseurope.org/knowledge-hub/plastics-the-facts-2022/ [accessed 14 August 2023].

Plastics Europe. 2019. Plastics – the Facts 2019: An analysis of European plastics production, demand and waste data. Retrieved October 23, 2023, from https://plasticseurope.org/wp-content/uploads/2021/10/2019-Plastics-the-facts.pdf [accessed 14 August 2023].

Prajapati, A., Narayan Vaidya, A., & Kumar, A. R. (2022). Microplastic properties and their interaction with hydrophobic organic contaminants: a review. Environmental Science and Pollution Research, 29(33), 49490–49512. https://doi.org/10.1007/s11356-022-20723-y

Prata, J. C., da Costa, J. P., Lopes, I., Duarte, A. C., & Rocha-Santos, T. (2020). Environmental exposure to microplastics: An overview on possible human health effects. Science of The Total Environment, 702, 134455. https://doi.org/10.1016/j.scitotenv.2019.134455

Proctor & Gamble (P&G). (n.d.). Environmental – Waste. https://www.pginvestor.com/esg/environmental/plastic-packaging/default.aspx [accessed 17 September 2023].

Prüst, M., Meijer, J., & Westerink, R. H. S. (2020). The plastic brain: neurotoxicity of micro- and nanoplastics. Particle and Fibre Toxicology, 17(1), 24. https://doi.org/10.1186/s12989-020-00358-y

Ramli Sulong, N. H., Mustapa, S. A. S., & Abdul Rashid, M. K. (2019). Application of expanded polystyrene (EPS) in buildings and constructions: A review. Journal of Applied Polymer Science, 136(20). https://doi.org/10.1002/app.47529

Ramsperger, A. F. R. M., Bergamaschi, E., Panizzolo, M., Fenoglio, I., Barbero, F., Peters, R., Undas, A., Purker, S., Giese, B., Lalyer, C. R., Tamargo, A., Moreno-Arribas, M. V., Grossart, H.-P., Kühnel, D., Dietrich, J., Paulsen, F., Afanou, A. K., Zienolddiny-Narui, S., Eriksen Hammer, S., … Laforsch, C. (2023). Nano- and microplastics: a comprehensive review on their exposure routes, translocation, and fate in humans. NanoImpact, 29, 100441. https://doi.org/10.1016/j.impact.2022.100441

Reynolds, C., & Ryan, P. G. (2018). Micro-plastic ingestion by waterbirds from contaminated wetlands in South Africa. Marine Pollution Bulletin, 126, 330–333. https://doi.org/10.1016/j.marpolbul.2017.11.021

Rochman, C. M., Brookson, C., Bikker, J., Djuric, N., Earn, A., Bucci, K., Athey, S., Huntington, A., McIlwraith, H., Munno, K., De Frond, H., Kolomijeca, A., Erdle, L., Grbic, J., Bayoumi, M., Borrelle, S. B., Wu, T., Santoro, S., Werbowski, L. M., … Hung, C. (2019). Rethinking microplastics as a diverse contaminant suite. Environmental Toxicology and Chemistry, 38(4), 703–711. https://doi.org/10.1002/etc.4371

Rochman, C. M., Tahir, A., Williams, S. L., Baxa, D. V., Lam, R., Miller, J. T., Teh, F.-C., Werorilangi, S., & Teh, S. J. (2015a). Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Scientific Reports, 5(1), 14340. https://doi.org/10.1038/srep14340

Rochman, C. M., Tahir, A., Williams, S. L., Baxa, D. V., Lam, R., Miller, J. T., Teh, F.-C., Werorilangi, S., & Teh, S. J. (2015b). Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Scientific Reports, 5(1), 14340. https://doi.org/10.1038/srep14340

Saeedi, M. (2023). How microplastics interact with food chain: a short overview of fate and impacts. Journal of Food Science and Technology. https://doi.org/10.1007/s13197-023-05720-4

Schartel, B., Wilkie, C. A., & Camino, G. (2017). Recommendations on the scientific approach to polymer flame retardancy: Part 2—Concepts. Journal of Fire Sciences, 35(1), 3–20. https://doi.org/10.1177/0734904116675370

Schirinzi, G. F., Pérez-Pomeda, I., Sanchís, J., Rossini, C., Farré, M., & Barceló, D. (2017). Cytotoxic effects of commonly used nanomaterials and microplastics on cerebral and epithelial human cells. Environmental Research, 159, 579–587. https://doi.org/10.1016/j.envres.2017.08.043

Schwarz, A. E., Ligthart, T. N., Boukris, E., & van Harmelen, T. (2019). Sources, transport, and accumulation of different types of plastic litter in aquatic environments: A review study. Marine Pollution Bulletin, 143, 92–100. https://doi.org/10.1016/j.marpolbul.2019.04.029

Shoshitaishvili, B. (2021). From Anthropocene to Noosphere: The Great Acceleration. Earth's Future, 9(2). https://doi.org/10.1029/2020EF001917

Shrivastava, A. (2018). Introduction to Plastics Engineering. Introduction to Plastics Engineering, 1–16. https://doi.org/10.1016/B978-0-323-39500-7.00001-0

Shruti, V. C., Pérez-Guevara, F., Elizalde-Martínez, I., & Kutralam-Muniasamy, G. (2021). Current trends and analytical methods for evaluation of microplastics in stormwater. Trends in Environmental Analytical Chemistry, 30, e00123. https://doi.org/10.1016/j.teac.2021.e00123

Singh, B., & Sharma, N. (2008). Mechanistic implications of plastic degradation. Polymer Degradation and Stability, 93(3), 561–584. https://doi.org/10.1016/j.polymdegradstab.2007.11.008

Smiroldo, G., Balestrieri, A., Pini, E., & Tremolada, P. (2019). Anthropogenically altered trophic webs: alien catfish and microplastics in the diet of Eurasian otters. Mammal Research, 64(2), 165–174. https://doi.org/10.1007/s13364-018-00412-3

Smyth, K., Drake, J., Li, Y., Rochman, C., Van Seters, T., & Passeport, E. (2021). Bioretention cells remove microplastics from urban stormwater. Water Research, 191, 116785. https://doi.org/10.1016/j.watres.2020.116785

SpecialChem. (2020). Density of plastics: Technical properties. Omnexus: The material selection platform. https://omnexus.specialchem.com/polymerproperties/properties/density [accessed 15 May 2023].

Sperling, L.H. (2006). Introduction to physical polymer science (4th ed). Hoboken, NJ: John Wiley & Sons, Inc.

Stoll, T., Stoett, P., Vince, J., & Hardesty, B. D. (2020). Governance and Measures for the Prevention of Marine Debris. In Handbook of Microplastics in the Environment (pp. 1–23). Springer International Publishing. https://doi.org/10.1007/978-3-030-10618-8_26-1

Surfrider Foundation. (n.d.). Hold on to your butt! (#HOTYB). https://www.pacificrim.surfrider.org/our-campaigns/hold-on-to-your-butt [accessed 18 September 2023].

Syberg, K., Hansen, S. F., Christensen, T. B., & Khan, F. R. (2018). Risk Perception of Plastic Pollution: Importance of Stakeholder Involvement and Citizen Science (pp. 203–221). https://doi.org/10.1007/978-3-319-61615-5_10

Tasseron, P., Begemann, F., Joosse, N., van der Ploeg, M., van Driel, J., & van Emmerik, T. (2023). Amsterdam urban water system as entry point of river plastic pollution. Environmental Science and Pollution Research, 30(29), 73590–73599. https://doi.org/10.1007/s11356-023-26566-5

Thammatorn, W., & Palić, D. (2022). Potential Risks of Microplastic Fomites to Aquatic Organisms with Special Emphasis on Polyethylene-Microplastic-Glyphosate Exposure Case in Aquacultured Shrimp. Applied Sciences, 12(10), 5135. https://doi.org/10.3390/app12105135

Thiele, C. J., Hudson, M. D., Russell, A. E., Saluveer, M., & Sidaoui-Haddad, G. (2021). Microplastics in fish and fishmeal: an emerging environmental challenge? Scientific Reports, 11(1), 2045. https://doi.org/10.1038/s41598-021-81499-8

Thompson, R. C., Moore, C. J., vom Saal, F. S., & Swan, S. H. (2009). Plastics, the environment and human health: current consensus and future trends. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 2153–2166. https://doi.org/10.1098/rstb.2009.0053

Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W. G., McGonigle, D., & Russell, A. E. (2004). Lost at Sea: Where Is All the Plastic? Science, 304(5672), 838–838. https://doi.org/10.1126/science.1094559

Tian, L., Jinjin, C., Ji, R., Ma, Y., & Yu, X. (2022). Microplastics in agricultural soils: sources, effects, and their fate. Current Opinion in Environmental Science & Health, 25, 100311. https://doi.org/10.1016/j.coesh.2021.100311

Turner, A. (2020). Foamed Polystyrene in the Marine Environment: Sources, Additives, Transport, Behavior, and Impacts. Environmental Science & Technology, 54(17), 10411–10420. https://doi.org/10.1021/acs.est.0c03221

U of T Trash Team. (n.d.). Pollution Prevention Projects. https://uofttrashteam.ca/preventionprojects/ [accessed 20 September 2023].

UNEP. (2023). Turning off the Tap: How the world can end plastic pollution and create a circular economy. https://www.unep.org/resources/turning-off-tap-end-plastic-pollution-create-circular-economy [accessed 2 September 2023].

van Emmerik, T. H. M., González-Fernández, D., Laufkötter, C., Blettler, M., Lusher, A., Hurley, R., & Ryan, P. G. (2023). Focus on plastics from land to aquatic ecosystems. Environmental Research Letters, 18(4), 040401. https://doi.org/10.1088/1748-9326/acc086

van Weert, S., Redondo-Hasselerharm, P. E., Diepens, N. J., & Koelmans, A. A. (2019). Effects of nanoplastics and microplastics on the growth of sediment-rooted macrophytes. Science of The Total Environment, 654, 1040–1047. https://doi.org/10.1016/j.scitotenv.2018.11.183

Verschoor, A. J. (2015). Towards a Definition of Microplastics: Considerations for the Specification of Physico-Chemical Properties. https://www.rivm.nl/bibliotheek/rapporten/2015-0116.pdf [accessed 2 May 2023].

Vikhareva, I. N., Buylova, E. A., Yarmuhametova, G. U., Aminova, G. K., & Mazitova, A. K. (2021). An Overview of the Main Trends in the Creation of Biodegradable Polymer Materials. Journal of Chemistry, 2021, 1–15. https://doi.org/10.1155/2021/5099705

Wang, L., Nabi, G., Yin, L., Wang, Y., Li, S., Hao, Z., & Li, D. (2021). Birds and plastic pollution: recent advances. Avian Research, 12(1), 59. https://doi.org/10.1186/s40657-021-00293-2

Wardlaw, C. M., Corcoran, P. L., & Neff, B. D. (2022). Factors influencing the variation of microplastic uptake in demersal fishes from the upper Thames River Ontario. Environmental Pollution, 313, 120095. https://doi.org/10.1016/j.envpol.2022.120095

Watson & Associates Economists Ltd. (2022). Population, Housing and Employment Growth Projection Study, 2021-2051. https://getinvolved.london.ca/20924/widgets/87832/documents/86405 [accessed 12 September 2023].

Webler, T., & Jakubowski, K. (2022). Attitudes, Beliefs, and Behaviors about Cigarette-Butt Littering among College-Aged Adults in the United States. International Journal of Environmental Research and Public Health, 19(13), 8085. https://doi.org/10.3390/ijerph19138085

Wilcox, C., Van Sebille, E., & Hardesty, B. D. (2015). Threat of plastic pollution to seabirds is global, pervasive, and increasing. Proceedings of the National Academy of Sciences, 112(38), 11899–11904. https://doi.org/10.1073/pnas.1502108112

Willis, K., Maureaud, C., Wilcox, C., & Hardesty, B. D. (2018). How successful are waste abatement campaigns and government policies at reducing plastic waste into the marine environment? Marine Policy, 96, 243–249. https://doi.org/10.1016/j.marpol.2017.11.037

Wolf, J., & Moser, S. C. (2011). Individual understandings, perceptions, and engagement with climate change: insights from in-depth studies across the world. WIREs Climate Change, 2(4), 547–569. https://doi.org/10.1002/wcc.120

World Economic Forum, Ellen MacArthur Foundation, and McKinsey & Company. (2016). The New Plastics Economy – Rethinking the future of plastics. https://www.ellenmacarthurfoundation.org/the-new-plastics-economy-rethinking-the-future-of-plastics [accessed 2 September 2023].

World Economic Forum. (2016). The New Plastics Economy: Rethinking the future of plastics. Retrieved October 16, 2023, from https://www3.weforum.org/docs/WEF_The_New_Plastics_Economy.pdf

World Wide Fund For Nature (WWF). (2023). Public Awareness. Retrieved November 1, 2023, from https://plasticsmartcities.org/public-awareness/

Wu, B., Wu, X., Liu, S., Wang, Z., & Chen, L. (2019). Size-dependent effects of polystyrene microplastics on cytotoxicity and efflux pump inhibition in human Caco-2 cells. Chemosphere, 221, 333–341. https://doi.org/10.1016/j.chemosphere.2019.01.056

Wu, Y., Guo, P., Zhang, X., Zhang, Y., Xie, S., & Deng, J. (2019). Effect of microplastics exposure on the photosynthesis system of freshwater algae. Journal of Hazardous Materials, 374, 219–227. https://doi.org/10.1016/j.jhazmat.2019.04.039

WWF. (n.d.). Your Plastic Diet. https://yourplasticdiet.org/ [accessed 20 September 2023].

Xanthos, M. (2010). Functional Fillers for Plastics (M. Xanthos, Ed.). Wiley. https://doi.org/10.1002/9783527629848

Xu, M., Halimu, G., Zhang, Q., Song, Y., Fu, X., Li, Y., et al. (2019). Internalization and toxicity: A preliminary study of effects of nanoplastic particles on human lung epithelial cell. Sci. Total Environ. 694, 133794. https://doi.org/10.1016/j.scitotenv.2019.133794

Yang, S., Zhou, M., Chen, X., Hu, L., Xu, Y., Fu, W., & Li, C. (2022). A comparative review of microplastics in lake systems from different countries and regions. Chemosphere, 286, 131806. https://doi.org/10.1016/j.chemosphere.2021.131806

Yang, W., Jannatun, N., Zeng, Y., Liu, T., Zhang, G., Chen, C., & Li, Y. (2022). Impacts of microplastics on immunity. Frontiers in Toxicology, 4. https://doi.org/10.3389/ftox.2022.956885

Yıldız, D., Yalçın, G., Jovanović, B., Boukal, D. S., Vebrová, L., Riha, D., Stanković, J., Savić-Zdraković, D., Metin, M., Akyürek, Y. N., Balkanlı, D., Filiz, N., Milošević, D., Feuchtmayr, H., Richardson, J. A., & Beklioğlu, M. (2022). Effects of a microplastic mixture differ across trophic levels and taxa in a freshwater food web: In situ mesocosm experiment. Science of The Total Environment, 836, 155407. https://doi.org/10.1016/j.scitotenv.2022.155407

Zhang, B., Yang, X., Chen, L., Chao, J., Teng, J., & Wang, Q. (2020). Microplastics in soils: a review of possible sources, analytical methods and ecological impacts. Journal of Chemical Technology & Biotechnology, 95(8), 2052–2068. https://doi.org/10.1002/jctb.6334

Zhang, K., Hamidian, A. H., Tubić, A., Zhang, Y., Fang, J. K. H., Wu, C., & Lam, P. K. S. (2021). Understanding plastic degradation and microplastic formation in the environment: A review. Environmental Pollution, 274, 116554. https://doi.org/10.1016/j.envpol.2021.116554

Zhao, X., Wang, J., Yee Leung, K. M., & Wu, F. (2022). Color: An Important but Overlooked Factor for Plastic Photoaging and Microplastic Formation. In Environmental Science and Technology (Vol. 56, Issue 13, pp. 9161–9163). American Chemical Society. https://doi.org/10.1021/acs.est.2c02402

Zimmermann, L., Göttlich, S., Oehlmann, J., Wagner, M., & Völker, C. (2020). What are the drivers of microplastic toxicity? Comparing the toxicity of plastic chemicals and particles to Daphnia magna. Environmental Pollution, 267, 115392. https://doi.org/10.1016/j.envpol.2020.115392

Zon, N. F., Iskendar, A., Azman, S., Sarijan, S., & Ismail, R. (2018). Sorptive behaviour of chromium on polyethylene microbeads in artificial seawater. MATEC Web of Conferences, 250, 06001. https://doi.org/10.1051/matecconf/201825006001

Appendix A: LittaTrap MaPs/MPs Database

Reference the attached electronic file: (Appendix_A_Data_Base*.xlsx).

Appendix B: Wind Speed and Precipitation Data With Location MaPs and MPs.

Season	Location	Number.MaPs	Number.MPs	Total.Precipitation (mm)	Avg.Windspeed (km/h)
Standard	Ivey Park	26	6	115.8	13.7
Standard	Inner Queens	89	20	115.8	13.7
Standard	Outer Queens	10	8	115.8	13.7
Standard	Bathurst	59	29	115.8	13.7
Standard	Carfrae	7	12	115.8	13.7
Standard	Dufferin	31	26	115.8	13.7
Autumn	Ivey Park	11	3	72.7	18.2
Autumn	Inner Queens	45	195	72.7	18.2
Autumn	Outer Queens	33	54	72.7	18.2
Autumn	Bathurst	152	144	72.7	18.2
Autumn	Carfrae	11	35	72.7	18.2
Autumn	Dufferin	22	75	72.7	18.2
Winter	Ivey Park	5	26	38.4	18.3
Winter	Inner Queens	23	72	38.4	18.3
Winter	Outer Queens	33	53	38.4	18.3
Winter	Bathurst	86	93	38.4	18.3
Winter	Carfrae	28	139	38.4	18.3
Winter	Dufferin	37	359	38.4	18.3
Spring	Ivey Park	20	67	226.9	14.5
Spring	Inner Queens	48	83	226.9	14.5
Spring	Outer Queens	51	41	226.9	14.5
Spring	Bathurst	158	136	226.9	14.5
Spring	Carfrae	19	88	226.9	14.5
Spring	Dufferin	65	111	226.9	14.5
Summer	Ivey Park	9	32	11.4	13.1
Summer	Inner Queens	62	213	11.4	13.1
Summer	Outer Queens	59	80	11.4	13.1
Summer	Bathurst	113	131	11.4	13.1
Summer	Carfrae	19	18	11.4	13.1
Summer	Dufferin	119	144	11.4	13.1

Appendix C: FTIR Results Database

Slide Label	Description	Common Plastic?	FTIR Result - main plastic/fibre material	If cellulosic material, ~1105 cm-1 peak present?	File Name
BATH SP 1	White Fragment	Y	PP	N/A	DC_BATH_SP_WHITE_FRAGMENT
DUFF SP 6	Purple Fragment	Y	ACRYLIC	N/A	DC_DUFF_SP_6
DUFF SP 5	Yellow Fragment	Y	ALKYD	N/A	DC_DUFF_SP_5
DUFF SP 4	Black Rubbery Fragment	N	LIKELY RUBBER/NOT INFRARED ACTIVE	N/A	DC_DUFF_SP_4
BATH SP 2	Yellow Fragment	Y	PP	N/A	DC_BATH_SP_2
BATH SP 3	Pink Fragment	Y	PE	N/A	DC_BATH_SP_3
BATH SP 1	Blue Fragment	Y	PE	N/A	PATR_BATH_SP_1
INQUEENS SP 7	Green Fragment	Y	PP	N/A	PATR_INQUEENS_SP_7
INQUEENS SP 8	Red Fragment	Y	ACRYLIC	N/A	PATR_INQUEENS_SP_8
INQUEENS SP 9	Blue Film	Y	PE	N/A	PATR_INQUEENS_SP_9
IVEY SP 10	Translucent Fragment	N	SILICONE RUBBER	N/A	DC_IVEY_SP_10
IVEY SP 11	Black Film-Like Fragment	Y	PE & PP	N/A	DC_IVEY_SP_11
IVEY SP 12	Green Fragment	Y	PP	N/A	DC_IVEY_SP_12
CAR SP 13	White Fragment	Y	POLYVINYLCHLORIDE	N/A	DC_CAR_SP_13
CAR SP 14	Translucent Fragment	Y	PE	N/A	DC_CAR_SP_14
CAR SP 15	Translucent Blue Fragment	Y	PE	N/A	DC_CAR_SP_15
CAR SP 16	White Fragment	Y	POLYVINYLCHLORIDE	N/A	DC_CAR_SP_16
CAR SP 17	Translucent Blue Fragment	Y	PE	N/A	DC_CAR_SP_17
CAR SP 18	Black Fragment	N	LIKELY RUBBER/NOT INFRARED ACTIVE	N/A	DC_CAR_SP_18
BATH SUM 19	Red Fragment	Y	PE	N/A	DC_BATH_SUM_19
BATH SUM 20	Transluent Green Fragment	Y	PE	N/A	DC_BATH_SUM_20
BATH SUM 21	Green Fragment	Y	PE		DC_BATH_SUM_21
BATH SUM 22	Grey Fragment	Y	PE	N/A	DC_BATH_SUM_22
BATH SUM 23	White Fragment	Y	ALKYD	N/A	DC_BATH_SUM_23
BATH SUM 24	Translucent Film	Y	PP	N/A	DC_BATH_SUM_24
INQUEENS SUM 25	Red Fragment	Y	PE	N/A	DC_INQUEENS_SUM_25
INQUEENS SUM 26	Black Fragment	Y	PE	N/A	DC_INQUEENS_SUM_26
INQUEENS SUM 27	Red Film	Y	PET	N/A	DC_INQUEENS_SUM_27
INQUEENS SUM 28	Green Fragment	Y	PP	N/A	DC_INQUEENS_SUM_28

INQUEENS SUM 29	Translucent Fragment	Y	PE	N/A	DC_INQUEENS_SUM_29
INQUEENS SUM 30	Blue Fragment	Y	PE	N/A	DC_INQUEENS_SUM_30
OUTQUEENS SUM 31	Gold Film	Y	PP	N/A	DC_OUTQUEENS_SUM_31
OUTQUEENS SUM 32	Pink Fragment	Y	PP	N/A	DC_OUTQUEENS_SUM_32
OUTQUEENS SUM 33	Grey Fragment	Y	PE	N/A	DC_OUTQUEENS_SUM_33
OUTQUEENS SUM 34	Black Fragment	Y	PP	N/A	DC_OUTQUEENS_SUM_34
OUTQUEENS SUM 35	Pink Fragment	Y	PP	N/A	DC_OUTQUEENS_SUM_35
OUTQUEENS SUM 36	Pink Fragment	Y	PP	N/A	DC_OUTQUEENS_SUM_36
DUFF SUM 37	Black Fragment	Y	PP	N/A	DC_DUFF_SUM_37
DUFF SUM 38	Blue Film	Y	PP	N/A	DC_DUFF_SUM_38
DUFF SUM 39	Pink Fragment	Y	EPDM	N/A	DC_DUFF_SUM_39
DUFF SUM 40	Red Fragment	Y	PP	N/A	DC_DUFF_SUM_40
DUFF SUM 41	Orange Fragment	Y	PA	N/A	DC_DUFF_SUM_41
DUFF SUM 42	Black Fragment	Y	PE	N/A	DC_DUFF_SUM_42
IVEY SUM 43	Translucent Fragment	Y	PDMS	N/A	DC_IVEY_SUM_43
IVEY SUM 44	Grey Fragment	Y	EPOXY RESIN	N/A	DC_IVEY_SUM_44
IVEY SUM 45	Black Fragment	Y	POLYSTYRENE	N/A	DC_IVEY_SUM_45
IVEY SUM 46	Translucent Fragment	Y	PE	N/A	DC_IVEY_SUM_46
CAR F 47	White Fragment	Y	POLYVINYLCHLORIDE	N/A	DC_CAR_SUM_47
CAR F 48	Transparent Fragment	Y	PP	N/A	DC_CAR_SUM_48
CAR F 49	Red Fragment	Y	UREA RESIN	N/A	DC_CAR_SUM_49
CAR F 50	Pink Fragment	Y	PE	N/A	DC_CAR_SUM_50
CAR F 51	Translucent Fragment	N	SILICONE RUBBER	N/A	DC_CAR_SUM_51
OUTQUEENS SP 52	Yellow Fragment	Y	ALKYD	N/A	DC_OUTQUEENS_SP_52
OUTQUEENS SP 53	Pink Fragment	Y	PE	N/A	DC_OUTQUEENS_SP_53
OUTQUEENS SP 54	Pink Fragment	Y	POLYBUTADIENE	N/A	DC_OUTQUEENS_SP_54
OUTQUEENS SP 55	Black Fragment	N	CELLULOSE	Y	DC_OUTQUEENS_SP_55
IVEY SP 56	Red Fragment	Y	ACRYLIC	N/A	DC_IVEY_SP_56
IVEY SP 57	Transparent Film	Y	POLYSTYRENE	N/A	PATR_IVEY_ST_57
INQUEENS ST 58	Black Fragment	N	MATCHES TO ETHYL CYANOFORMATE	N/A	DC_INQUEENS_ST_58
BATH ST 59	Grey Fragment	Y	ABS	N/A	PATR_BATH_ST_59
DUFF ST 60	White Fragment	Y	PET	N/A	PATR_DUFF_ST_60
DUFF ST 61	Cylindrical Rubber Fragment	N	LIKELY RUBBER/NOT INFRARED ACTIVE	N/A	DC_DUFF_ST_61

DUFF ST 62	Transparent Bead	Y	PE	N/A	PATR_DUFF_ST_62
DUFF ST 63	Red Fragment	Y	POLYSTYRENE	N/A	DC_DUFF_ST_63
DUFF ST 64	Green Fragment	Y	POLYSTYRENE	N/A	DC_DUFF_ST_64
INQUEENS F 65	Translucent Fragment	Y	PP	N/A	PATR_INQUEENS_F_65
INQUEENS F 66	Blue Fragment	Y	PP	N/A	DC_INQUEENS_F_66
INQUEENS F 67	Blue Fragment	Y	PE	N/A	PATR_INQUEENS_F_67
INQUEENS F 68	Blue Fragment	Y	PP	N/A	DC_INQUEENS_F_68
INQUEENS F 69	Green Fragment	Y	PP	N/A	PATR_INQUEENS_F_69
INQUEENS F 70	Translucent Fragment	Y	PP	N/A	PATR_INQUEENS_F_70
INQUEENS F 71	Green Rectangular Fragment	Y	POLYSTYRENE	N/A	DC_INQUEENS_F_71
INQUEENS F 72	Yellow Fragment	Y	PP	N/A	DC_INQUEENS_F_72
INQUEENS F 73	Transparent Fragment	Y	PP	N/A	DC_INQUEENS_F_73
INQUEENS F 74	Yellow Fragment	Y	PE	N/A	DC_INQUEENS_F_74
INQUEENS F 75	Yellow Fragment	Y	PE	N/A	DC_INQUEENS_F_75
OUTQUEENS F 76	White Fragment	Y	POLYSTYRENE	N/A	DC_OUTQUEENS_F_76
OUTQUEENS F 77	Green Film	Y	PET	N/A	DC_OUTQUEENS_F_77
OUTQUEENS F 78	Gold Film	Y	PET	N/A	DC_OUTQUEENS_F_78
OUTQUEENS F 79	Grey Fragment	Y	ACRYLIC RESIN	N/A	DC_OUTQUEENS_F_79
OUTQUEENS F 80	Green Fragment	Y	ABS	N/A	DC_OUTQUEENS_F_80
OUTQUEENS F 81	White Fragment	Y	POM	N/A	DC_OUTQUEENS_F_81
OUTQUEENS F 82	Yellow Fragment	Y	PE	N/A	DC_OUTQUEENS_F_82
BATH F 83	Blue Fragment	Y	EPOXY RESIN	N/A	PATR_BATH_F_83
BATH F 84	Blue Film	Y	PE	N/A	DC_BATH_F_84
BATH F 85	Blue Fragment	Y	ABS	N/A	DC_BATH_F_85
BATH F 86	White Fragment	Y	PP	N/A	DC_BATH_F_86
BATH F 87	Translucent Orange	Y	POLYSTYRENE	N/A	DC_BATH_F_87
BATH F 112	Gold Film	Y	ALKYD	N/A	DC_BATH_F_112
BATH F 113	Green Film	Y	PE	N/A	DC_BATH_F_113
BATH F 114	Purple Fragment	Y	PP	N/A	DC_BATH_F_114
BATH F 115	Black Fragment	N	DODECANE	N/A	DC_BATH_F_115
BATH F 116	Black Fragment	Y	ABS	N/A	DC_BATH_F_116
DUFF F 88	Yellow Fragment	Y	ACRYLIC	N/A	DC_DUFF_F_88
DUFF F 89	Green Fragment	Y	PE	N/A	PATR_DUFF_F_89

DUFF F 90	Pink Fragment	Y	PP	N/A	PATR_DUFF_F_90
DUFF F 91	Yellow Fragment	Y	ACRYLIC	N/A	PATR_DUFF_F_91
DUFF F 92	Red Film	Y	PET	N/A	PATR_DUFF_F_92
DUFF F 93	Black Fragment	N	LIKELY RUBBER/NOT INFRARED ACTIVE	N/A	DC_DUFF_F_93
DUFF F 94	Black Fragment	N	LIKELY RUBBER/NOT INFRARED ACTIVE	N/A	DC_DUFF_F_94
DUFF F 95	Yellow Fragment	Y	ACRYLIC	N/A	DC_DUFF_F_95
DUFF F 96	Blue Fragment	Y	ACRYLIC	N/A	DC_DUFF_F_96
DUFF F 97	White Fragment	Y	ACRYLIC	N/A	DC_DUFF_F_97
BATH W 98	Blue Fragment	Y	POLYSTYRENE	N/A	DC_BATH_W_98
BATH W 99	White Fragment	Y	PP	N/A	DC_BATH_W_99
BATH W 100	White Fragment	Y	PP	N/A	DC_BATH_W_100
BATH W 101	Grey Fragment	Y	PE	N/A	DC_BATH_W_101
BATH W 102	Blue Fragment	Y	PE	N/A	DC_BATH_W_102
BATH W 103	Red Fragment	Y	PET	N/A	DC_BATH_W_103
BATH W 104	White Fragment	Y	PE	N/A	DC_BATH_W_104
BATH W 105	Grey Fragment	Y	PE	N/A	DC_BATH_W_105
BATH W 106	Green Fragment	Y	PP	N/A	DC_BATH_W_106
INQUEENS W 107	White Fragment	Y	PE	N/A	DC_INQUEENS_W_107
INQUEENS W 108	Blue Fragment	Y	PE	N/A	DC_INQUEENS_W_108
INQUEENS W 109	Black Fragment	Y	PE	N/A	DC_INQUEENS_W_109
INQUEENS W 110	White Fragment	Y	POLYVINYLCHLORIDE	N/A	DC_INQUEENS_W_110
INQUEENS W 111	Blue Fragment	Y	PE	N/A	DC_INQUEENS_W_111
DUFF W 117	White Fragment	Y	POLYVINYLCHLORIDE	N/A	DC_DUFF_W_117
DUFF W 118	White Fragment	Y	ABS	N/A	DC_DUFF_W_118
DUFF W 119	Black Fragment	Y	PE	N/A	DC_DUFF_W_119
DUFF W 120	Black Fragment	Y	PE	N/A	DC_DUFF_W_120
DUFF W 121	Black Fragment	Y	PE	N/A	DC_DUFF_W_121
DUFF W 122	Black Fragment	N	LIKELY RUBBER/NOT INFRARED ACTIVE	N/A	
DUFF W 123	Black Fragment	N	LIKELY RUBBER/NOT INFRARED ACTIVE	N/A	DC_DUFF_W_123
DUFF W 124	Black Fragment	N	LIKELY RUBBER/NOT INFRARED ACTIVE		DC_DUFF_W_124
DUFF W 125	Blue Fragment	Y	PE	N/A	DC_DUFF_W_125
DUFF W 126	Red Fragment	Y	PE	N/A	DC_DUFF_W_126
DUFF W 127	Yellow Fragment	Y	PA	N/A	DC_DUFF_W_127
OUTQUEENS W 128	Blue Fragment	Y	ACRYLIC	N/A	DC_OUTQUEENS_W_128

OUTQUEENS W 129	Translucent Film	Y	PP	N/A	DC_OUTQUEENS_W_129
OUTQUEENS W 130	Translucent Film	Y	PET	N/A	DC_OUTQUEENS_W_130
CAR W 131	Green Fragment	Y	PE	N/A	DC_CAR_W_131
CAR W 132	Green Fragment	Y	PP	N/A	DC_CAR_W_132
CAR W 133	White Fragment	Y	POLYVINYLCHLORIDE	N/A	DC_CAR_W_133
CAR W 134	Green Fragment	Y	PE	N/A	DC_CAR_W_134
CAR W 135	White Fragment	Y	PP	N/A	DC_CAR_W_135
CAR W 136	Blue Fragment	Y	PP	N/A	DC_CAR_W_136
CAR W 137	Pink Fragment	Y	PP	N/A	DC_CAR_W_137
IVEY F 138	Translucent Fragment	Y	PDMS	N/A	DC_IVEY_F_138
IVEY F 139	Green Fragment	Y	PE	N/A	DC_IVEY_F_139
OUTQUEENS ST 140	Transparent Fragment	Y	PES	N/A	DC_OUTQUEENS_ST_140
OUTQUEENS ST 141	Grey Fragment	Y	POLYSTYRENE	N/A	DC_OUTQUEENS_ST_141
CAR ST 142	Yellow Fragment	Y	PE	N/A	DC_CAR_ST_142
CAR SUM 143	Red Fragment	Y	PVC	N/A	DC_CAR_SUM_143
CAR SUM 144	Blue Fragment	Y	PE	N/A	DC_CAR_SUM_144
CAR SUM 145	Pink Fragment	Y	PE	N/A	DC_CAR_SUM_145
CAR SUM 146	Green Fragment	Y	PE	N/A	DC_CAR_SUM_146
CAR SUM 147	White Fragment	Y	PP	N/A	DC_CAR_SUM_147
CAR SUM 148	White Fragment	Y	POLYVINYLCHLORIDE	N/A	DC_CAR_SUM_148
CAR SUM 149	Blue Fragment	Y	PE	N/A	DC_CAR_SUM_149
IVEY W 150	Pink Fragment	Y	PE	N/A	DC_IVEY_W_150
FTIR DUFF F 1	Red Fibre	N	CASHMERE	N/A	DUFF_F_FTIR_1
FTIR DUFF F 2	Clear Fibre	Y	PE	N/A	DUFF_F_FTIR_2
FTIR DUFF F 3	Clear Fibre	Y	PE	N/A	DUFF_F_FTIR_3
FTIR INQUEENS F 4	Green Fibre	Y	PE	N/A	INQUEENS_F_FTIR_4
FTIR IVEY F 5	Clear Fibre	Y	PP	N/A	IVEY_F_FTIR_5
FTIR OUTQUEENS F 6	Clear Fibre	Y	PLA	N/A	OUTQUEENS_F_FTIR_6
FTIR OUTQUEENS F 7	Red Fibre	Y	PP	N/A	OUTQUEENS_F_FTIR_7
FTIR BATH F 8	Clear Fibre	Y	PE	N/A	BATH_F_FTIR_8
FTIR BATH F 9	Blue Fibre	N	HAIR	N/A	BATH_F_FTIR_9
FTIR CAR F 10	Clear Fibre	Y	PP	N/A	CAR_F_FTIR_10
FTIR DUFF ST 11	Clear Fibre	Y	PE	N/A	DUFF_ST_FTIR_11
FTIR INQUEENS ST 12	Clear Fibre	Y	PP	N/A	INQUEENS_ST_FTIR_12

FTIR INQUEENS ST 13	Green Fibre	Y	PP	N/A	INQUEENS_ST_FTIR_13
FTIR IVEY ST 14	Clear Fibre	Y	PE	N/A	IVEY_ST_FTIR_14
FTIR OUTQUEENS ST 15	Clear Fibre	Y	POLYVINYL ACETATE	N/A	IVEY_ST_FTIR_15
FTIR BATH ST 16	Clear Fibre	N	CELLULOSE	Y	DC_BATH_ST_FTIR_16
FTIR CAR ST 17	Clear Fibre	Y	PP	N/A	CAR_ST_FTIR_17
FTIR DUFF W 18	Blue Fibre	N	HAIR	N/A	DUFF_W_FTIR_18
FTIR INQUEENS W 19	Clear Fibre	Y	PP	N/A	INQUEENS_W_FTIR_19
FTIR INQUEENS W 20	Black Fibre	Y	PP	N/A	INQUEENS_W_FTIR_20
FTIR IVEY W 21	Clear Fibre	N	HAIR	N/A	IVEY_W_FTIR_21
FTIR OUTQUEENS W 22	Clear Fibre	Y	PE	N/A	DC_OUTQUEENS_W_FTIR_22
FTIR OUTQUEENS W 23	Black Fibre	Y	PE	N/A	DC_OUTQUEENS_W_FTIR_23
FTIR BATH W 24	Clear Fibre	Y	PE	N/A	DC_BATH_W_FTIR_24
FTIR CAR W 25	Clear Fibre	Y	PE	N/A	DC_CAR_W_FTIR_25
FTIR DUFF SP 26	Green Fibre	Y	PP	N/A	DC_DUFF_SP_FTIR_26
FTIR INQUEENS SP 27	Clear Fibre	Y	PET	N/A	DC_INQUEENS_SP_FTIR_27
FTIR IVEY SP 28	Clear Fibre	Y	PET	N/A	DC_IVEY_SP_FTIR_28
FTIR IVEY SP 29	Clear Fibre	Y	PET	N/A	DC_IVEY_SP_FTIR_29
FTIR IVEY SP 30	Green Fibre	Y	ACRYLONITRILE	N/A	DC_IVEY_SP_FTIR_30
FTIR OUTQUEENS SP 31	Clear Fibre	Y	COTTON	N/A	DC_OUTQUEENS_SP_FTIR_31
FTIR BATH SP 32	Green Fibre	Y	PP	N/A	DC_CAR_SP_FTIR_32
FTIR CAR SP 33	Red Fibre	Y	NYLON	N/A	DC_BATH_SP_FTIR_33
FTIR DUFF SUM 34	Clear Fibre	Y	PET	N/A	DC_DUFF_SUM_FTIR_34
FTIR DUFF SUM 35	Clear Fibre	Y	ACETATE FIBRE	N/A	DC_DUFF_SUM_FTIR_35
FTIR INQUEENS SUM 36	Grey Fibre	Y	PET	N/A	DC_INQUEENS_SUM_FTIR_36
FTIR INQUEENS SUM 37	Green Fibre	Y	EPDM	N/A	DC_INQUEENS_SUM_FTIR_37
FTIR INQUEENS SUM 38	Translucent Fibre	Y	NYLON	N/A	DC_INQUEENS_SUM_FTIR_38
FTIR IVEY SUM 39	Translucent Fibre	Y	ACRYLONITRILE	N/A	DC_IVEY_SUM_FTIR_39

FTIR IVEY SUM 40	Black Fibre	Y	PET	N/A	DC_IVEY_SUM_FTIR_40
FTIR IVEY SUM 41	Red Fibre	Y	PP	N/A	DC_IVEY_SUM_FTIR_41
FTIR OUTQUEENS SUM 42	Purple Fibre	Y	ACRYLONITRILE	N/A	DC_OUTQUEENS_SUM_FTIR_42
FTIR OUTQUEENS SUM 43	Translucent Fibre	Y	PET	N/A	DC_OUTQUEENS_SUM_FTIR_43
FTIR OUTQUEENS SUM 44	Green Fibre	Y	PP	N/A	DC_OUTQUEENS_SUM_FTIR_44
FTIR BATH SUM 45	Translucent Fibre	Y	PET	N/A	DC_BATH_SUM_FTIR_45
FTIR BATH SUM 46	Translucent Fibre	Y	PET	N/A	DC_BATH_SUM_FTIR_46
FTIR BATH SUM 47	Blue Fibre	Y	PET	N/A	DC_BATH_SUM_FTIR_47
FTIR CAR SUM 48	Translucent Fibre	Y	ACETATE FIBRE	N/A	DC_CAR_SUM_FTIR_48
FTIR CAR SUM 49	Translucent Fibre	Y	ACRYLONITRILE	N/A	DC_CAR_SUM_FTIR_49
FTIR CAR SUM 50	Translucent Fibre	N	HAIR	N/A	DC_CAR_SUM_FTIR_50
PBLANK 03	Translucent Fibre	Y	CELLULOSE	Y	DC_PROCESSING_BLANK_01
PBLANK 04	Translucent Fibre	Y	CELLULOSE	Y	DC_PROCESSING_BLANK_02
MBLANK 05	Translucent Fibre	N	COTTON	Y	DC_MICROSCOPE_BLANK_04
FIELDBLANK WINTER 02	Blue Fibre	N	COTTON	Y	DC_FIELDBLANK_WINTER02_07
FIELDBLANK SUMMER 02	Translucent Fibre	N	COTTON	Y	DC_FIELDBLANK_SUMMER02_09

Appendix D: FTIR Spectra from all samples.

Reference the attached electronic file: (Appendix_D_AC10323_SPECTRA*.ppt).

Curriculum Vitae

Name:	Nina Kozikowski
Post-secondary Education and Degrees:	University of Western Ontario London, Ontario, Canada 2017-2021 B.A.., Honours Double Major Geology & Physical Geography and Environment
Honours and Awards:	International Learning Award 2019
	Robbert W. Hodder International Geoscience Field Experience Award 2019
Related Work Experience	Teaching Assistant The University of Western Ontario 2021-2023

Publications & Conference Presentations:

Kozikowski, N. Efficiency of Plastic Pollution Control in Stormwater Drains of the Thames River Watershed, Great Lakes Basin, Canada. 7th International Marine Debris Conference, Busan, South Korea. September 18th 2022.