Determining the Economic Cost of Single-Use Plastic Waste in Canada

IISD REPORT

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The authors assume responsibility for the analytical approach and calculations presented in this report. The findings are derived from the best available data and established methodological frameworks, and every effort has been made to ensure rigour and accuracy. At the same time, the results are subject to standard data and modelling constraints.

Executive Summary

This study assessed the quantities and economic costs of single use plastic (SUP) waste in Canada, including costs incurred across municipal solid waste and wastewater management systems, litter cleanup activities, and the losses in ecosystem goods and services (EGS). This analysis aims to provide federal, provincial, and municipal decision-makers with the evidence needed to support actions that reduce SUP pollution in Canada. The study focuses on eight common SUP types: plastic bottles, bottle caps, disposable hot cups and lids, disposable cold cups and lids, foam trays, cigarette butts, vaping devices and their cartridges, and tampon applicators.

The data collection process included desk research to identify publicly available waste data and engaging municipal solid waste and wastewater management workers through interviews, consultations, and data contributions. To understand the cost burden of SUPs in the solid waste management systems in Canada, we focused our study on a sample subset of eight Canadian municipalities: Halifax, Toronto, Winnipeg, Brandon, Edmonton, Banff, Squamish, and Yellowknife. These municipalities were selected to represent a broad range of community sizes and geographic contexts. While more municipalities were initially contacted, these eight represent the subset that responded affirmatively to participating. Through direct engagement with these municipalities, we were able to better understand how plastic waste is collected and categorized in daily operations, as well as the challenges that pose barriers to collecting accurate data on SUPs in Canada.

To engage the wastewater sector, we created a survey and circulated it to municipalities across Canada, which we used to collect both quantitative and qualitative data on the types of SUPs present in the wastewater sector and how they are managed. Eleven wastewater managers from municipalities in Manitoba, Ontario, Nova Scotia, New Brunswick, British Columbia, and Alberta responded to the survey. Their input provided valuable information on how SUPs are screened out of wastewater, which SUP items are most encountered, and the key barriers to tracking SUPs within wastewater systems.

Another component of this project was the development of an Excel-based tool, the *Plastic Waste Cost Calculator*, that allows local authorities to organize and aggregate data related to the costs of SUPs and plastic waste in general for their locality or across multiple jurisdictions. The tool provides a practical, interactive interface for local authorities to calculate their annual SUP management spending across various responsible organizations, accounting for waste management costs across the residential, commercial and industrial, and wastewater sectors. It was informed by inputs from municipal waste management experts from eight municipalities across Canada.

Our analysis also included understanding occurrences and costs of SUPs discarded as litter, which is another pathway through which SUPs are sometimes disposed of. We analyzed litter audit data from the eight municipalities that made up our subset in solid waste management analysis, in addition to a data scan based on the citizen science efforts. This analysis included data from user-reported cleanups and litter collected from the International Trash Trapping Network from the Trash Information and Data for Education and Solutions database. To fill spatial gaps in the citizen science dataset, we also included the most recent study of macroplastic pollution in the Canadian High Arctic, conducted in 2018 and 2019. This analysis allowed us to understand how the eight selected SUPs end up in the environment, potentially causing environmental damage or contributing to cleanup costs.

To account for indirect costs of SUP waste, we completed an analysis of EGS losses that may be caused by SUP waste, with a focus on less-studied EGS impacts in terrestrial and freshwater ecosystems. EGS are both tangible and intangible benefits humans obtain from ecosystems, such as fuel, food, clean air and water, and aesthetic and spiritual value. Although information on the impacts of macro and microplastics on EGS provided by terrestrial and freshwater ecosystems is very limited overall (not to mention for specific SUPs), and this scientific field is still evolving, there are known effects of microplastics on soil health and primary productivity with implications for agricultural production and food security. These effects provide a starting point for estimating the impacts of plastics on EGS in Canadian ecosystems. If plastic pollution, including SUP litter and plastics entering wastewater treatment systems, is not effectively addressed, it is likely to lead to increasing concentrations of plastic particles in Canadian agricultural soils, creating long-term challenges for agricultural production. These include significant impacts on photosynthesis, primary productivity, and crop yields, with estimated economic losses for major crops such as wheat and maize reaching tens of millions of dollars annually, or potentially more than billions of dollars if all sources of microplastics in agricultural soils are considered.

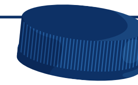
Major findings for SUPs reviewed in this study are presented below.

Figure ES1. Summary of key results for specific SUPs

Plastic bottles

Plastic bottles are one of the most commonly tracked SUPs across municipalities due to their high recycling potential, but they are often not recycled.

In shoreline cleanups, plastic bottles are one of the most commonly found litter items, especially in rural areas. If every Canadian disposed of the median number of bottles found in our sample, it would cost **~CAD 6.3 million[a] per year in the residential garbage stream alone.**



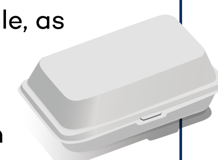
Bottle caps

Bottle caps are less consistently recyclable than bottles because they are made from different materials and there are varying recycling capacities between municipalities. Bottle caps are also less commonly tracked in waste audits than the bottles they belong to. As litter, they are especially common in rural areas and alongside lakes.

Cold cups and lids

Disposable cold cups and lids pose a challenge for tracking because of their large variation in shape, size, and weight.

Even though cold cups are nearly all recyclable, they often get disposed of in garbage or as litter. In shoreline cleanups, these cups are one of the most commonly found litter items by weight.



Foam trays

Foam trays are common in the food industry but are rarely recyclable, as are other foam-based SUPs.

Foam trays are often found in high quantities as fragments in litter because of their tendency to break into small pieces, including microplastics in the environment.

In shoreline cleanups, foam trays and their fragments are consistently common across all environment types. By mass, they are one of the top three litter items found in trash traps.

Hot cups and lids

A typical disposable hot cup is only composed of 5% plastic. The rest of the cup is made from paper or cardboard materials.

If every Canadian disposed of the median number of hot cups found in our sample, it would cost **~CAD 7 million[a] per year in the residential garbage stream alone.**

Cigarette butts

Cigarette butts are the most commonly littered item in Canada by count across jurisdictions. In cities, they account for over 95% of litter in trash traps by count.

Over 5,000 tons of cigarette butt waste is produced annually in Canada (Physicians for a Smoke-Free Canada, 2020).

Vaping devices

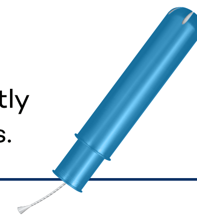
Vaping devices pose a fire hazard when disposed of because they contain batteries.

Vaping cartridges frequently end up in wastewater and have to be screened out in treatment plants. Some of these cartridges enter the wastewater stream through schools, indicating use by students.

Tampon applicators

Tampon applicators should only be disposed of in the garbage, but they are often found in wastewater screenings.

Tampon applicators are an undertracked SUP, frequently excluded from waste audits.



[a] Based on the median cost value derived from the sample of six Canadian municipalities.

Source: Authors.

Main Findings and Recommendations for Tracking SUP Waste in Canada

1. Overall, there is a lack of consistent, item-level data on SUPs in garbage, recycling, and wastewater streams across Canadian municipalities. Waste audits are seen as the best way to address this issue; however, they are resource-intensive and typically require dedicated funding that most small and mid-sized municipalities do not have access to. We recommend providing incentives, including funding, for additional waste audits across the garbage, recycling, and wastewater streams to better understand specific SUPs and inform efforts to reduce their prevalence. One way to do this would be to have dedicated waste audit funding available from provincial, territorial, or federal governments that also considers the specific needs and circumstances of remote municipalities.
2. Plastics have a high volume-to-weight ratio, and it is volume—not weight—that drives the costs of managing SUP waste in municipal solid waste systems. However, waste reporting and audits are typically based on weight, tracking annual tonnages rather than space occupied. While weight standardizes measurement, it does not reflect the operational burden of high-volume, low-weight materials like SUPs. Incorporating volumetric measurements into waste tracking and audits, along with volumetric adjustments in cost allocation, would provide a more accurate picture of the cost burden of SUPs.
3. Establishing standard practices for SUP-related data collection methods and item categories across communities would be a significant step forward in generating valuable data sets. The Excel-based tool developed as part of this project can contribute toward this goal.
4. Wipes are appearing frequently in wastewater screenings and cause multiple issues to wastewater systems, such as sewer blockages. Although wipes were not part of the initial

SUPs of focus of the study, they were identified as significant by respondents to our survey on SUPs in wastewater. We recommend that a standard for flushability of wipes—ideally at the global level, or at a minimum nationally—be developed to ensure clear, uniform standards and address the costs faced by wastewater systems.

Recommendations on the Use and Further Development of the Excel-based *Plastic Waste Cost Calculator*

A plastic waste cost calculator tool was developed and is accessible here.

Our recommendations for the use of this tool are as follows:

1. Local authorities can use this tool as a framework to aggregate data across multiple organizations responsible for waste management in their locality. For example, if different organizations handle recycling versus garbage, or manage multi-unit residences versus single-family homes, they can consolidate their data using this tool. This allows local authorities to gain a more holistic view of the total costs of plastic waste management in their area. It is worth noting that, when aggregating information, data access and sharing between entities—especially private waste collectors or managers—must be resolved on a case-by-case basis through agreements, assumptions, or the use of proxy data.
2. Similarly, provincial, federal, or regional authorities could use this Excel-based tool to track and aggregate plastic waste quantities and costs across Canadian municipalities on a larger scale, supporting policy advocacy related to plastic waste management. It is important that existing data from provincial and federal sources be analyzed first before requiring municipalities to complete new surveys. Harmonizing data collection can reduce the reporting burden on local authorities by minimizing duplicate requests and preventing the need to submit similar information multiple times to different agencies.
3. Currently, the tool utilizes weight-based allocation for cost calculations. However, SUPs are typically high-volume but lightweight materials. We wish to draw attention to this design element and recommend that future iterations of the tool incorporate volumetric measurements and adjustments. In doing so, municipal waste management departments—particularly operational staff—should be engaged to help develop appropriate volume conversion factors, such as those based on material densities or other practical proxies for volume.

Observations and Recommendations on Estimating EGS Losses From SUP Waste in Canada

1. We recommend improved tracking of plastic waste and its chemical composition (including polymer type and additives) at both macro and micro levels across Canadian solid waste management and wastewater systems, litter, soils, and aquatic environments.

2. Scientific studies should be conducted to understand risk (through dose-response studies) and determine the mechanisms of effects of macro and microplastic effects on a full range of biological processes in terrestrial and freshwater environments. Research should also prioritize the effects of chemical additives to more fully evaluate effects on ecosystems and, therefore, EGS losses.
3. Improved monitoring of macro- and microplastics in waste streams and the environment is essential to understanding impacts on EGS. However, plastics in the environment originate from multiple sources and pathways, so a degree of uncertainty will remain when attributing EGS impacts to specific SUPs such as bottles, cups, and vaping devices.
4. Specific consideration should also be given to human health costs alongside broader ecosystem impacts (i.e., on wildlife, plants, and microbial communities) as these costs can be substantial and provide a strong case for mitigating plastic pollution.
5. Based on the availability of scientific results, further research may examine risks to other unique values attributed to ecosystems—for instance, the cultural ties of Indigenous Peoples to key species and water resources—to ensure a more comprehensive understanding of EGS losses from plastic pollution.

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Abbreviations and Acronyms

DRS	deposit return systems
ECCC	Environment and Climate Change Canada
EGS	ecosystem goods and services
EPR	extended producer responsibility
EPS	expanded polystyrene
GPP	gross primary productivity
HDPE	high-density polyethylene
IWSFG	International Water Services Flushability Working Group
MMSM	Multi-Material Stewardship Manitoba
MT	million tonnes
OECD	Organisation for Economic Co-operation and Development
PAH	polycyclic aromatic hydrocarbons
PET	polyethylene terephthalate
PP	polypropylene
SUP	single-use plastic
TIDES	Trash Information and Data for Education and Solutions

1.0 Introduction

1.1 Project Background

This study assesses the quantities and economic costs of single use plastic (SUP) waste in Canada, including costs incurred across municipal solid waste and wastewater management systems, litter cleanup activities, and associated losses in ecosystem goods and services (EGS) with a focus on terrestrial and freshwater ecosystems. This analysis aims to provide federal, provincial, and municipal decision-makers with the evidence needed to support actions that reduce SUP pollution in Canada, including policies surrounding extended producer responsibility (EPR) and deposit return systems (DRS).

Drawing on the collected data, we also developed an Excel-based tool that enables municipalities to estimate and visualize their plastic waste management costs across disposal pathways using local data. Much of the information included in this report is derived from interviews conducted with waste management staff from municipalities across Canada, as is described in Section 2. Methods.

What Are SUPs?

An SUP is a product made at least partially from plastic that is designed to be used once, or just a few times before being discarded. Some of the most common SUPs include wet wipes, coffee cups, beverage bottles, and food packaging (Environment and Climate Change Canada [ECCC], 2025). These items are sometimes recyclable but often end up in landfills and wastewater systems, or as litter (World Wide Fund for Nature [WWF], 2021). Because these items are typically lightweight, low-value, and not economically viable to recycle at scale, they contribute disproportionately to global plastic pollution (ECCC, 2025). Their lightweight nature also means they take up a large volume per unit weight, making them potentially expensive for municipalities to handle after they are discarded. SUPs also frequently end up in wastewater treatment facilities, which can add to the costs of handling SUP waste (Barry Orr, personal communication, January 12, 2026).

SUPs Examined in This Study

For this project, we chose eight common SUP items to analyze, selected based on their prevalence and the diversity of their uses:

- plastic bottles
- bottle caps
- disposable hot cups and lids
- disposable cold cups and lids

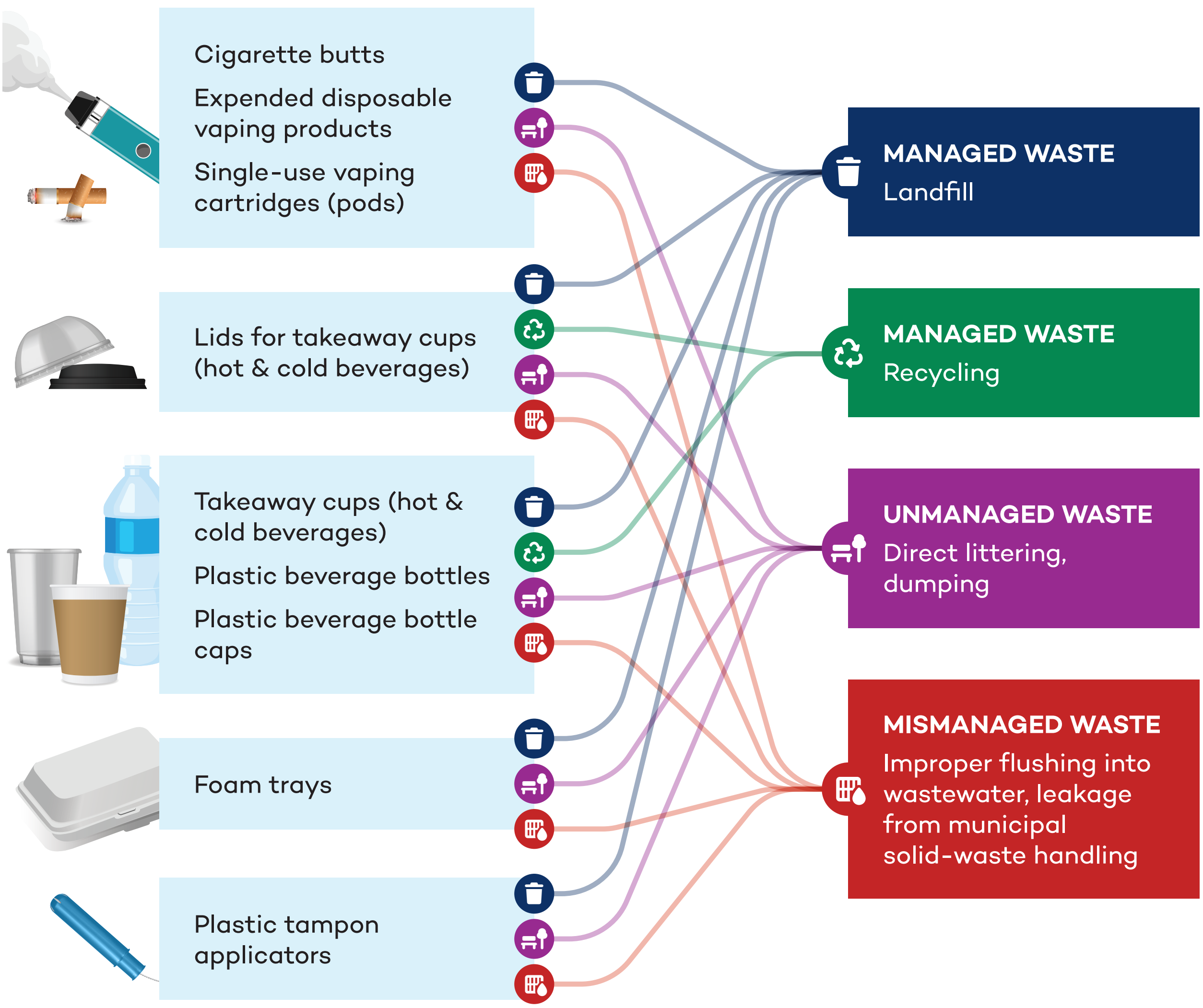
- foam trays
- cigarette butts
- vaping devices and their cartridges
- tampon applicators

These SUP categories can vary significantly in ways that affect their management, recycling, and environmental costs, even within a single SUP type. For example, disposable cups can be made from different materials, including polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), or paper with plastic linings, and these differences influence how they are handled at end of life: PET and some PP plastics are more widely accepted in recycling streams (Rabson, 2024), whereas polystyrene foam is rarely recycled and paper cups with plastic linings often cannot be processed in standard paper recycling because the lining must be separated first, increasing costs and complicating recycling infrastructure ("Coffee cups among many items," 2016; Davis, 2019). Moreover, some SUPs on our list—particularly disposable vaping devices—present additional waste management challenges because they contain electronic components and batteries. These devices typically include lithium-ion batteries, which classify them as electronic waste (e-waste) in many systems and require specialized disposal, although many jurisdictions are still developing clear regulations for how to collect and process these devices at end of life (Perrone, 2023). Products containing batteries are known to pose additional safety risks in waste management, such as fire hazards (Perrone, 2023). Certain SUPs, like tampon applicators, may contain biohazard risks and will also need to be managed differently. For detailed information on each selected SUP, including their composition, plastic content, volumes of waste, and years that the products can persist in the environment, see Appendix A.

1.2 Pathways of SUPs After Use

Figure 1 illustrates typical waste pathways that SUPs will follow after their use. SUPs may be either disposed of correctly (which would incur costs through the waste management system) or incorrectly (which would incur cleanup costs and environmental costs). Both cases involve direct and indirect costs. The pathways by which these costs would be incurred, along with examples of what types of costs might be involved, are shown in Figure 1.

Figure 1. Pathways of SUP items after being discarded, and examples of associated costs



EXAMPLES OF COSTS

Managed SUP Waste

Direct:

- Labour cost at waste facilities, landfill management, incineration
- Explosions from vaping devices and damages to infrastructure

Indirect:

- GHG emissions
- Health impacts for workers

Unmanaged and Mismanaged SUP Waste

Direct:

- Costs of litter cleanups
- Damages to sewers and wastewater infrastructure

Indirect:

- Loss of aesthetic, recreation and tourism values
- Health impacts on animals and humans, including through water contamination
- Impact on the carbon cycle

Source: Authors.

SUPs in Solid Waste Management Systems

For the purposes of the study, four streams of waste were analyzed for the presence and cost of SUPs: garbage, recycling, wastewater, and litter. In many municipalities, more waste streams exist (like organic waste), but for our purposes and for our focus on macroplastics, these four streams were considered the most relevant.

Box 1. Variations in solid waste management systems set up in Canadian cities

There are some consistencies in how municipalities manage waste streams across Canada, but variations do exist from municipality to municipality. Canadian municipalities generally differentiate between residential and non-residential waste and manage only the residential stream. However, definitions of what is included in the residential stream can vary between municipalities. In some cities, large multi-unit residential buildings are included in residential, but in many others, these buildings are not included. Many municipalities have cutoffs for how many units can be in a residential building before it is no longer included in the municipally managed stream (often between four and six).

Once (residential) waste is collected, there can also be differences in how garbage and recycling are managed. Many larger municipalities will have both landfills and recycling facilities locally, but smaller municipalities may need to ship some of their waste out. This is more common with recycling than garbage because some municipalities do not have the capacity to manage the recycling stream locally. While the specific set of municipalities we focused on all have access to landfills with the ability to measure mass, some small Canadian municipalities may not have scales at their local landfills. This can introduce greater uncertainty in reported quantities.

Garbage and recycling waste streams described below are typically separated into residential and non-residential streams. Residential waste refers to waste produced by households, which may be either collected by the municipality or self-hauled by the resident to a depot, transfer station, or other disposal facility (Statistics Canada, 2019). Residential waste streams consist of single-family homes, duplexes, and, in some cases, multi-unit residential buildings. However, in many cases, the multi-unit residential buildings are included in the non-residential (commercial) stream (see Box 1). Non-residential waste "refers to the amount of non-hazardous waste generated by all sources excluding the residential waste stream," such as industrial and commercial sources. Industrial waste refers to waste produced by primary and secondary industries, like manufacturing (Statistics Canada, 2019). Commercial waste refers to waste produced by commercial businesses, like restaurants and shops, institutions like schools and hospitals, and sometimes includes large apartment buildings (Statistics Canada, 2019). In most of the cities investigated, only the residential waste stream is managed by the municipality, while non-residential waste streams are contracted to private companies. However, our study and tool development deal with other waste streams in addition to the municipally managed residential stream.

Garbage

The garbage waste stream is the "default" waste stream, where all waste that cannot be recycled, composted, or otherwise diverted from landfill goes. Depending on the waste diversion options available in a particular municipality, garbage may include more or fewer plastic items. For example, in some municipalities, bottle caps can be recycled, but in others, they are considered garbage because of limited recycling capacity. Often, recyclable items end up in the garbage stream even when diversion potential exists because of mistakes or a lack of education at the individual level. Approximately 97% of garbage ends up in a landfill, with the remaining 3% being incinerated (Government of Canada, 2024).

Recycling

The recycling waste stream consists of items that can be broken down into reusable materials. In each municipality, the capabilities for which items can be recycled are different. However, some of the most common recyclable items include plastic bottles, disposable cups, and other beverage containers. Increasingly, efforts are being made in Canada to implement EPR and DRS. EPR refers to programs that place the responsibility for proper end-of-life disposal on the producer. For example, the producer of a disposable plastic bottle would be responsible for where that bottle goes and how it is managed at the end of its use. DRS refers to programs in which consumers pay a deposit on a container they get back when they return it at the end of use. For example, instead of throwing a beverage container in the garbage, they would return it to a designated location to get their deposit back. Typically, these programs fall under provincial or territorial jurisdiction (Bottle Bill Resource Guide, n.d.).

SUPs in Wastewater Management Systems

An additional pathway that discarded SUPs sometimes take is through the wastewater system. This is what happens when SUPs are discarded incorrectly by flushing them down the drain. While this is always discouraged, all municipalities have had this happen (e.g., for plastic wet wipes or tampon applicators) on occasion. In these cases, the SUPs will end up in wastewater management facilities where they are often screened out and can sometimes cause damage to the facility's infrastructure ("Don't flush your flushable wipes", 2023). This creates costs for removal from the wastewater system and transportation to a proper facility where garbage is meant to be managed (e.g., landfill).

SUP Litter in the Environment

Litter consists of waste that is improperly disposed of or managed, and that is either purposefully or accidentally not properly placed in a waste receptacle. Some of the most commonly littered items are cigarette butts and coffee cups (see Section 3.3 SUP Occurrences in the Environment—Litter). Sometimes litter gets washed into storm drains and can end up in wastewater treatment systems (see Section 3.3). In some municipalities, people are hired to periodically clean up litter, but this work is often left up to volunteers. Much of the data available about litter comes from initiatives like beach cleanups, trash traps, and litter surveys.

1.3 Impacts of Plastics on the Terrestrial and Freshwater Ecosystems

SUPs are entering the environment as litter, through leakages from landfills, and through sewer systems (including during sewer overflows in rain events). The Organisation for Economic Co-operation and Development (OECD) (2022) assumes that approximately 15% of all litter is not cleaned up by street sweeping or storm drain catchments in high-income countries and, therefore, enters the environment. In all cases, these items enter the environment as macroplastics (> 5 millimetres in size) and can then subsequently degrade into microplastics (< 5 millimetres in size). Micro- and macroplastics impact all types of ecosystems, but for this project, our primary focus is on terrestrial and freshwater ecosystems.

The SUPs reviewed in this study can persist in the environment all the way from decades (for cellulose acetate fibres in cigarette butts) to centuries for items such as plastic bottle caps and foam trays (for details see Appendix A). This affects living organisms at all levels of biological organization, from individual to population and ecosystem levels. Subsequently, by interfering with natural processes, SUPs, whether in macro- or micro-forms, have a high potential to negatively affect the provision of EGS. EGS are the benefits humans receive from nature or, as defined by Boyd and Banzhaf (2007), "components of nature, directly enjoyed, consumed, or used to yield human well-being."[1]

The effects of both macro- and microplastics on environmental health are being actively studied (ECCC, 2020). It is important to note that SUPs examined in this study are made from a range of polymer types (e.g., polyethylene terephthalate [PET], polypropylene [PP], high-density polyethylene [HDPE], expanded polystyrene [EPS]), each with potentially different environmental impacts. The presence of chemical additives meant to enhance the performance of a plastic product, like plasticizers, flame retardants, pigments, and antioxidants, can further influence and complicate these effects (Hahladakis et al., 2018). Below is a high-level overview of known effects of both macro- and microplastics at the individual, population, and ecosystem levels.

[1] This is a definition of final EGS. For final EGS, the user of the service is an economic unit that includes businesses, governments, and households (United Nations et al., 2024). Examples of final EGS include harvested crops as a food source, recreation in natural areas, and flood protection that reduces damage to homes and infrastructure. In contrast, there are also intermediate EGS, "in which the user of the ecosystem services is an ecosystem asset and where there is a connection to the supply of final ecosystem services" (United Nations et al., 2024, p. 139). For example, soil quality regulation service (intermediate EGS) influences crop biomass production, which, in turn, is a final EGS directly consumed by businesses, governments, and households.

Effects of Micro- and Macroplastics, Including SUP Items, at Individual, Population, and Ecosystem Levels

Macroplastic pollution, including single-use items, can harm wildlife at every level, from individual organisms to entire ecosystems, with the strongest evidence at the sub-organismal and individual levels (Bucci et al., 2020; Senko et al., 2020). Animals frequently ingest plastic (Wilcox et al., 2018), become entangled in it (Blettler & Mitchell, 2021; Gregory, 2009; Gündoğdu et al., 2019; Jagiello et al., 2019), or are smothered by it (Green et al., 2015; Lamb et al., 2018), leading to internal injuries like lacerations, ulcers, and intestinal blockages (Poppi et al., 2012). These physical traumas often result in reduced feeding and death across various species, including birds, turtles, fish, and mammals (Blettler & Mitchell, 2021; Jagiello et al., 2019; Kühn & van Franeker, 2020; Murphy et al., 2025; Provencher et al., 2015; Wilcox et al., 2018). While these impacts begin with individuals, they can cause population-level declines, particularly for species with small populations or slow reproductive rates, such as sea turtles and seals (Baker et al., 2024; Bucci et al., 2020; Murphy et al., 2024; Perez-Venegas et al., 2021).

Beyond individual harm, macroplastics can alter biological communities by creating "novel habitats" (Haney & Rochman, 2025). Floating debris can support unique groups of microbes and invertebrates, potentially acting as a vehicle for invasive species to spread across oceans (Barnes, 2002; Rech et al., 2016; Zettler et al., 2013). In heavily polluted rivers, plastic can even degrade water quality enough to change the diversity of fish communities (Abdullah et al., 2022). At the ecosystem level, plastic debris can smother complex habitats like coral reefs (Lamb et al., 2018) and disrupt essential nutrient cycling by covering sediment and interfering with natural chemical reactions (Green et al., 2015). In streams, it can even change how energy flows by altering the behaviour of invertebrates and slowing down the decomposition of organic matter (Batista et al., 2022).

As these larger plastics linger in the environment, they undergo mechanical, chemical, and biological degradation (Andrady, 2017; Dimassi et al., 2022; Julienne et al., 2019; Liro et al., 2023). Physical forces like wave action and river currents shred items, while ultraviolet radiation from the sun makes plastic brittle and prone to breaking (Andrady, 2017; Dimassi et al., 2022; Liro et al., 2023). This process transforms macroplastics into microplastics (particles smaller than 5 mm), which are more bioavailable, and a greater diversity of organisms can ingest or interact with them. A study of the Great Lakes found microplastics in all tested fish species, demonstrating the widespread presence of microplastic contamination (Milne et al., 2024).

Once inside an organism, microplastics cause damage ranging from altered gene expression to impaired development and reproduction (Bucci et al., 2020; Koelmans et al., 2022; Mehinto et al., 2022). They trigger internal inflammation, oxidative stress, and a false sense of fullness that prevents animals from eating actual food (Koelmans et al., 2022; Mehinto et al., 2022). Furthermore, microplastics are chemically active; they contain original manufacturing additives like flame retardants and plasticizers (Hermabessiere et al., 2017), and they also soak up environmental toxins like DDT, metals, and pharmaceuticals from the surrounding water

(Godoy et al., 2019; Puckowski et al., 2021; Teuten et al., 2009). Consequently, microplastics act as vectors, delivering concentrated doses of these pollutants directly into the bodies of living organisms (Atugoda et al., 2021).

Inevitably, as micro- and macroplastic concentrations increase in ecosystems, the risks to ecological functioning grow, along with the impacts on the provision of EGS that humans rely on for well-being and for the functioning of the economy. However, the research on cascading effects of macro- and microplastics on the EGS underpinning our economy and well-being has been limited to date (Sridharan et al., 2021). In the present study, we map the connections between plastic pollution and EGS to capture a diverse and wide-ranging set of impacts expected to occur as plastic pollution grows (see Section 3.4, Ecosystem Losses and Impacts). We also estimate the potential effects of microplastic pollution—of which SUPs are a contributor—on agricultural soils and the provisioning service of crop production in Canada, as this represents a clear scientifically supported link between plastic contamination and EGS provision in terrestrial ecosystems and has great economic, social, and environmental relevance for Canada as a major agricultural producer (Government of Canada, 2025).

1.4 Review of Literature on Costs of Single-Use Plastics

The social costs of plastic waste to the economy have been estimated in several studies across different regions (for example, Fiji [Raes et al., 2023] and the United States [Lauer et al., 2026]). These studies focus on general plastic waste and, in terms of ecosystem services, primarily examine losses to marine ecosystems. Beaumont et al. (2019) quantified marine EGS from plastic pollution, and their widely cited study serves as the foundation for other studies that incorporate ecosystem-loss elements, including one in the United States recently conducted by Duke University (Lauer et al., 2026). That study found that the annual social cost of plastic to the United States is between USD 436 billion to USD 1.109 trillion per year (in 2025 dollars), which is likely an underestimate since "not all harms observed from plastic had documented costs in the literature at the time of this analysis in July 2025" (p. 2). The study outlined the critical costing gaps related to "human health impacts, loss of terrestrial ecosystem services, cost of recycling and incinerating plastic waste, and lowered property values" (p. 2, emphasis added). The same research identified that the research on the economic costs of plastic "has focused on marine ecosystems, overlooking costs to terrestrial ecosystems" (p. 19).

No studies were identified that specifically examine EGS losses in terrestrial and freshwater environments, which would be particularly relevant for Canada with its extensive land-based economic activities such as agriculture, inland nature tourism, and fisheries. There are also far fewer studies that focus on specific SUPs and their links to economic costs and EGS losses—a notable gap that limits the development of targeted strategies for particular SUPs.

In a global study, Sy (2023) estimated preliminary costs of both the economic and environmental burden of waste from plastic cigarette filters, bringing together available data from the World Bank and OECD on waste management costs (Kaza et al., 2018; OECD, 2022) and WWF on marine costs of plastic pollution (WWF, 2021). Sy suggests that the total cost of plastic pollution associated with cigarette filters in Canada is around USD 90 million, comprising both waste management costs and loss of ecosystem services over the lifetime of a cigarette filter (10 years). Annual waste management costs comprise 5% of this estimate, with the remainder being the loss of ecosystem services in the marine environment. Sy (2023, p. 3) also states that beyond the general and preliminary estimate provided in this research, "Optimal costing studies involve collecting data at the country level," which is the approach the present study adopts for Canada.

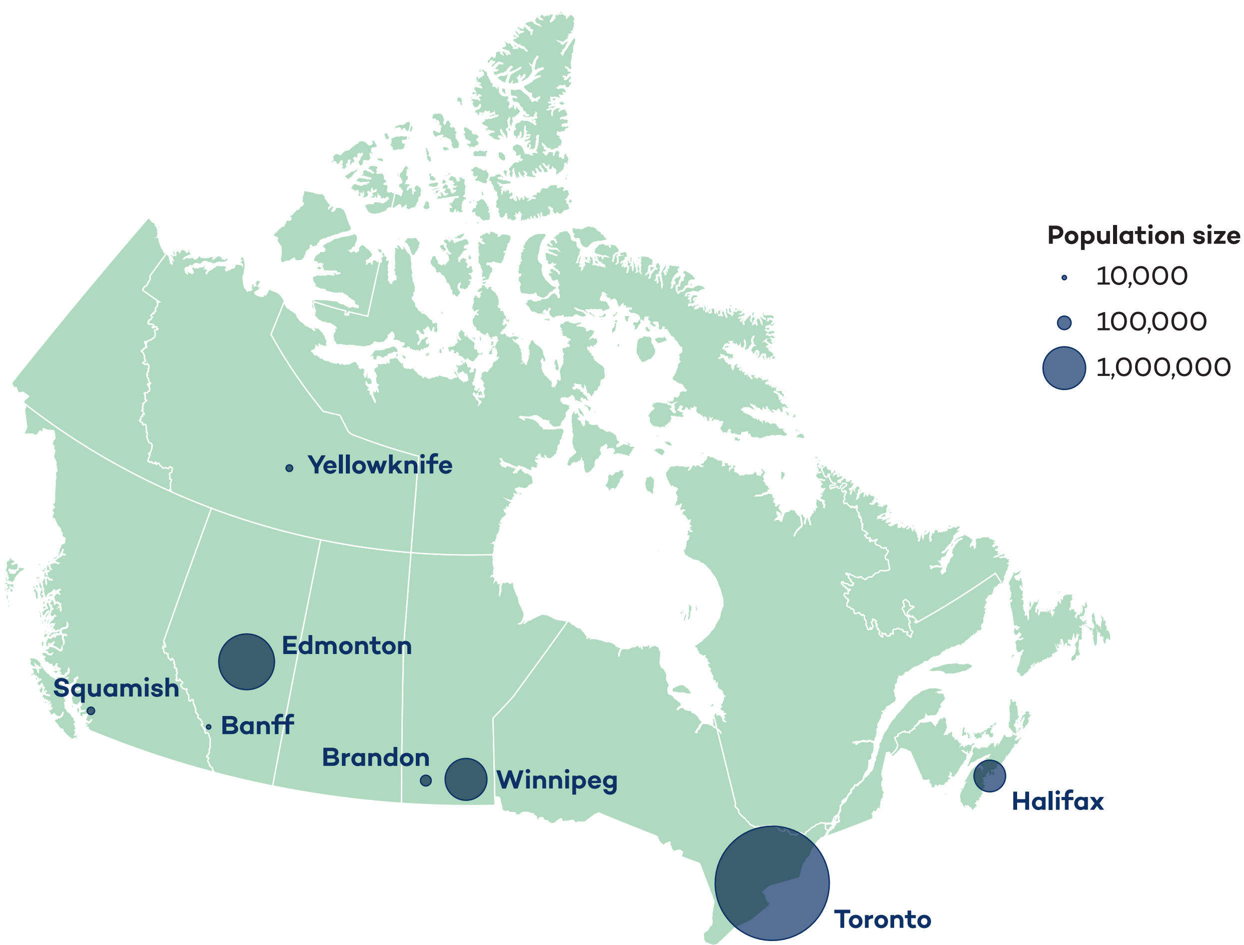
2.0 Study Methods

2.1 Data Collection and Analysis Process

Solid Waste Management

The cities selected as case studies for this project were selected to represent a diversity of geographic regions and sizes. The selected municipalities were Halifax, Toronto, Winnipeg, Brandon, Edmonton, Banff, Yellowknife, and Squamish (Figure 2). These were chosen to ensure that multiple major geographic regions of the country and municipality sizes—both large cities and small rural municipalities—were represented. While a further diversity of municipalities was initially contacted, the final set represents those that responded affirmatively.

Figure 2. Location of municipal case studies, scaled by population size



Source: Authors.

Waste Management Systems and Context for Selected Cities

The following section describes the solid waste management systems and other pertinent characteristics of each municipality, providing important context for the possible variations of the amounts of SUP waste generated per capita and the cost to manage it. This section draws significantly on interviews with municipal waste management workers as a form of data collection (Section 2.1.1.3).

Banff, Alberta

Banff is a small Alberta municipality with a highly variable population, due to tourism and the visitor-adjusted population. While the permanent population of Banff is roughly 10,000 (Statistics Canada, 2021), the municipality receives, on average, over 4 million visitors annually (Carla Bitz, personal communication, April 2, 2025). While Banff does have recycling options in place, visitors are less likely to be educated on how to dispose of waste appropriately, so they often throw recyclables in the garbage. To account for this confusion among recyclable and compostable single-use items, Banff centres its strategy around "single-use items" rather than "single-use plastics." An example of a single-use item could be a compostable coffee cup that is used once and then disposed of in a landfill, where it will not compost under typical landfill conditions. With no processing facilities in the national park, Banff also has to export all its waste from all streams for final handling to larger cities, like Calgary, which furthers the environmental implications of waste processing (like transport emissions).

Edmonton, Alberta

Edmonton is a city in Alberta with a population of over 1.5 million people (Statistics Canada, 2021). Edmonton has four streams of residential waste collection: food scraps, recycling, garbage, and seasonal yard waste (City of Edmonton, 2025a). The city provides only waste collection for the residential sector, which includes both single detached and multi-unit properties. Edmonton has a bylaw regarding single-use items (not just plastics), which took effect in 2023 (City of Edmonton, 2025c). This bylaw aims to reduce the use of single-use items, but not to eliminate their use entirely. It mostly focuses on items connected to the food service industry, like cups and cutlery, as well as other items, like single-use shopping bags. One of the implications is that restaurants must serve dine-in beverages in reusable tableware. Foam plates, cups, and containers are no longer allowed. As of April 2025, they are also incorporating EPR into their residential waste management by working with Circular Materials (City of Edmonton, 2025b). This applies to single-use items in the recycling stream.

Winnipeg, Manitoba

Winnipeg is a city of roughly 800,000 residents in Southern Manitoba (Statistics Canada, 2021). Winnipeg collects most residential garbage and recycling, excluding some multi-unit buildings. Recycling is processed domestically in a facility contracted to GFL Environmental Inc., a company that provides solid waste management services in Canada and parts of the United States (GFL, 2026). Waste audits are sometimes conducted by Multi-Material Stewardship Manitoba

(MMSM), but not through the city. MMSM is a not-for-profit organization that supports residential recycling in Manitoba under provincial EPR regulations (MMSM, 2025).

Brandon, Manitoba

Brandon is a small city in Manitoba with a population of roughly 60,000 (Statistics Canada, 2021). It offers both garbage and recycling for most residential waste (City of Brandon, 2024). Brandon is able to process all waste streams domestically, with the exception of some recyclable items that are shipped out for final processing to cities with greater capacity (City of Brandon, 2024).

Halifax, Nova Scotia

Halifax is the largest city in Atlantic Canada with a population of roughly half a million residents (Statistics Canada, 2021). The municipality operates a dual stream recycling system that accepts a broad range of materials, including plastic containers, paper, cardboard, metal cans, and glass bottles and jars. Curbside collection is provided for residential properties, including apartment buildings with up to six units. Larger buildings are required to arrange commercial services. Nova Scotia launched EPR for packaging and paper in December 2025. Circular Materials operates the program on behalf of producers.

Toronto, Ontario

Toronto is the largest city in Canada, located in Southern Ontario, with a very comprehensive waste management system that focuses on waste reduction, reuse, and activities that promote resource conservation and reduce environmental impacts. The system includes organic and yard waste, landfill, and recycling. The city can handle waste streams domestically. Toronto collects waste for the residential sector. It recently implemented a strategy in 2024 to reduce single-use and takeaway items, which applies to consumer-facing businesses, like restaurants (Toronto Waste Management Services, 2023). The rollout of this strategy includes initiatives like requiring customers to be asked before providing them with single-use cups and charging for plastic bags, and retail establishments are required to provide reusable bags and cups (Toronto Waste Management Services, 2023). EPR is now being implemented in Toronto with Circular Materials (Circular Materials, 2025).

Squamish, British Columbia

The District of Squamish is a small municipality in British Columbia of just over 30,000 people (Statistics Canada, 2021). In British Columbia, waste management strategies are mandated at the provincial level, providing a more standardized structure at the regional district level. Under the BC waste management system, municipalities like Squamish are mainly responsible for waste collection at households as well as streetscapes, while final waste disposal (e.g., landfills) is typically managed by regional districts. However, the District of Squamish is an exception, as it owns and operates its own landfill (District of Squamish, 2024). The District of Squamish has incorporated sampling of single-use items found in the regular waste composition audits it conducts at its landfill (District of Squamish, 2024). While they represent around 3% of the waste by weight on average for residential, industrial, commercial, and institutional (ICI) and multi-family homes, Squamish has found that it is through the streetscape bins that the majority of single-use items are brought to the landfill for disposal. The District of Squamish has signed up with Recycle BC to collect the curbside recycling material, which is managed through its EPR program (Recycle BC, 2024).

Yellowknife, Northwest Territories

Yellowknife is a small Northern municipality in the Northwest Territories with roughly 20,000 residents (Statistics Canada, 2021). Because of its small size and remoteness, the municipality does not have the same access to waste management resources as larger municipalities in the South. There is a local landfill, but recyclable items have to be shipped to recycling facilities in Alberta and British Columbia. Residents can drop off their recycling items at a local recycling station. Recycling rates have declined since the pandemic because it has become inconvenient for residents to manage waste without curbside pickup. Most plastic items in Yellowknife cannot be recycled; however, the municipality does have a program for recycling plastic bottles. People can bring their plastic bottles to collection containers at a depot for recycling.

Data Sources: Reports and publications

Table 1 presents the list of sources used in the study related to each municipality. We obtained publicly available data regarding waste streams from municipal websites and local reports. Some data was obtained from unpublished sources accessed with permission from municipal contacts. We particularly targeted data from waste audits in which the prevalence of items was explicitly broken down by material or SUP type. The total weights and costs of each waste stream provided in these reports are complete numbers encompassing the entire waste stream on an annual basis. For data on the breakdown of waste types in the stream, this was based on samples taken during waste audits commissioned by the municipalities. Standardizations were applied to the sample data we received to account for differences in sample size and units.

Table 1. List of waste audit reports, related waste and cost reporting from municipalities and other sources used in the study

City	Data sources
Banff	Ripley, S (2018)
Brandon	Tetra Tech (2024) City of Brandon (2024) City of Brandon (2025) MMSM (2025a) MMSM (2025b)
Edmonton	Not publicly available
Halifax	Divert Nova Scotia (2023a) Divert Nova Scotia (2023b) Divert Nova Scotia (2023c)
Squamish	Recycle BC (2024) District of Squamish (2024) Sperling Hansen Associates. (2025)
Toronto	City of Toronto (2024)
Winnipeg	City of Winnipeg (2024) MMSM (2025a) MMSM (2025b)
Yellowknife	City of Yellowknife (2018) Government of Northwest Territories (2024)

Source: Authors.

Interviews and Privately Held Data

Interviews were conducted with representatives from each municipality's waste management sector to ask about how waste is managed there and any particularities to consider when managing their data. The information provided in these interviews provided the basis for much of what is reported. We also used the interviews as an opportunity to inquire about any data that could be shared with us which is not publicly available. Some of the data in our final calculations was acquired via this channel and used in our calculations of averages and trends. In some cases, follow-up interviews were scheduled to clarify points about the data being shared and to ensure it was being correctly interpreted.

Data Transformations

The raw data collected was not all measured in consistent units; therefore, some transformations were applied for consistency and comparability. All weights were converted into units of kilograms for all waste types, excluding litter. Litter data was maintained as count data, as is the industry standard. The timeframe over which data was measured was converted to annual values. In some cases, data on specific SUPs of interest from the garbage and recycling streams was provided as count data rather than weight. In these cases, we converted the data to weight by using the average weight of the SUP of interest. For example, if the prevalence of water bottles in the waste stream was provided as count data, we would convert that to weight by using the average weight of a plastic water bottle (see Appendix A for details on each SUP).

Calculations were also done to standardize for population size. The population in each case study municipality that is serviced by waste collection was calculated using the average household size data from the 2021 Canadian census. This population data was then used to calculate per capita costs and quantities of specific types of SUP waste managed for each municipality, based on data availability. This allowed us to make comparisons and estimates independent of population size.

For analysis of specific SUPs, we saw some variation in category labelling in waste audits between municipalities. Most categories were consistent between municipalities, but we saw variation with foam trays and cold cups. Specifically, the variation we observed was due to levels of consolidation. For example, some municipalities had all cold cups in a single category, while others split them up by plastic type. To standardize for this, we aggregated the data to the level of least resolution. For example, all cold cup types were aggregated into a single category so that we could make accurate comparisons with municipalities that aggregated the data that way to begin with. The same method was applied to foam trays, where different styles of foam tray were aggregated to match the lowest resolution data in the set.

Wastewater Management

Wastewater systems are not officially a pathway for SUP disposal, which means that municipal waste management departments do not typically collect data on plastic waste in the wastewater system. However, SUPs frequently do end up in wastewater. To capture the costs associated with this phenomenon, we crafted a survey targeted at municipal wastewater facility workers to better quantify the extent of SUPs in wastewater (Appendix B). The goal of the survey was to collect data on which types of SUPs are commonly found in wastewater screenings as well as the costs associated with removing these SUPs from the system. To recruit respondents for the survey, we used snowball sampling, beginning by contacting a small number of wastewater management workers to pilot the survey and gather feedback. We then used referrals from our initial contacts to build our respondent base for the final version of the survey.

SUP Occurrences in the Environment—Litter

Litter data across Canadian municipalities is primarily collected by non-municipal organizations, like volunteer groups and non-governmental organizations. To understand the abundance of the select single-use macroplastics in the terrestrial and freshwater ecosystems in Canada, we used a combination of citizen science data and published survey data (Table 2).

Table 2. Summary of data sources used in the analysis

Type of data	Year	Sample size	Source	Citation
Shoreline cleanups	2024	656	TIDES	Ocean Conservancy (2024)
Literature surveys	2018 and 2019	15	Mallory et al. (2021)	Mallory et al. (2021)
Trash traps	2024	823	International Trash Trapping Network and TIDES	Ocean Conservancy (2024)

Source: Authors.

Table 3. Macroplastic product categories as described in Haney et al. (2025)

Category	Items	Material types
Smoking related	Cigarette butts, cigars, lighters, cigarette packaging, vapes	Plastic
Food related	Cups, bottles, jars, beer carriers, food packaging/wrappers, food trays, shopping bags	Plastic, foam
Medical/personal hygiene	Flosser/toothbrush, syringe, band aid, first aid, diaper, wipe, female hygiene, pill bottle, condom, gloves, facemask	Plastic, rubber
Sports	Toys, balls, balloons	Plastic, rubber
Fragment	Plastic, foam, rubber	Plastic

Category	Items	Material types
Dumping	Bottles (non-food), containers/drums, foam packaging, foam "peanuts," strapping band, baskets/crates, trash bag, carpet/large fabric, clothing, footwear, tire, pipes	Plastic, foam
Water activity	Fishing line, fishing hook/trap, rope, buoy	Plastic
Miscellaneous	Other plastic, foam	Plastic, foam

Source: Haney et al., 2025.

The citizen science data is from 2024 and includes user-reported cleanups and litter collected from the International Trash Trapping Network from the Trash Information and Data for Education and Solutions (TIDES) database (Ocean Conservancy, 2024). To fill spatial gaps in the citizen science data set, we also included the most recent study of macroplastic pollution in the Canadian High Arctic, conducted in 2018 and 2019 (Mallory et al., 2021).

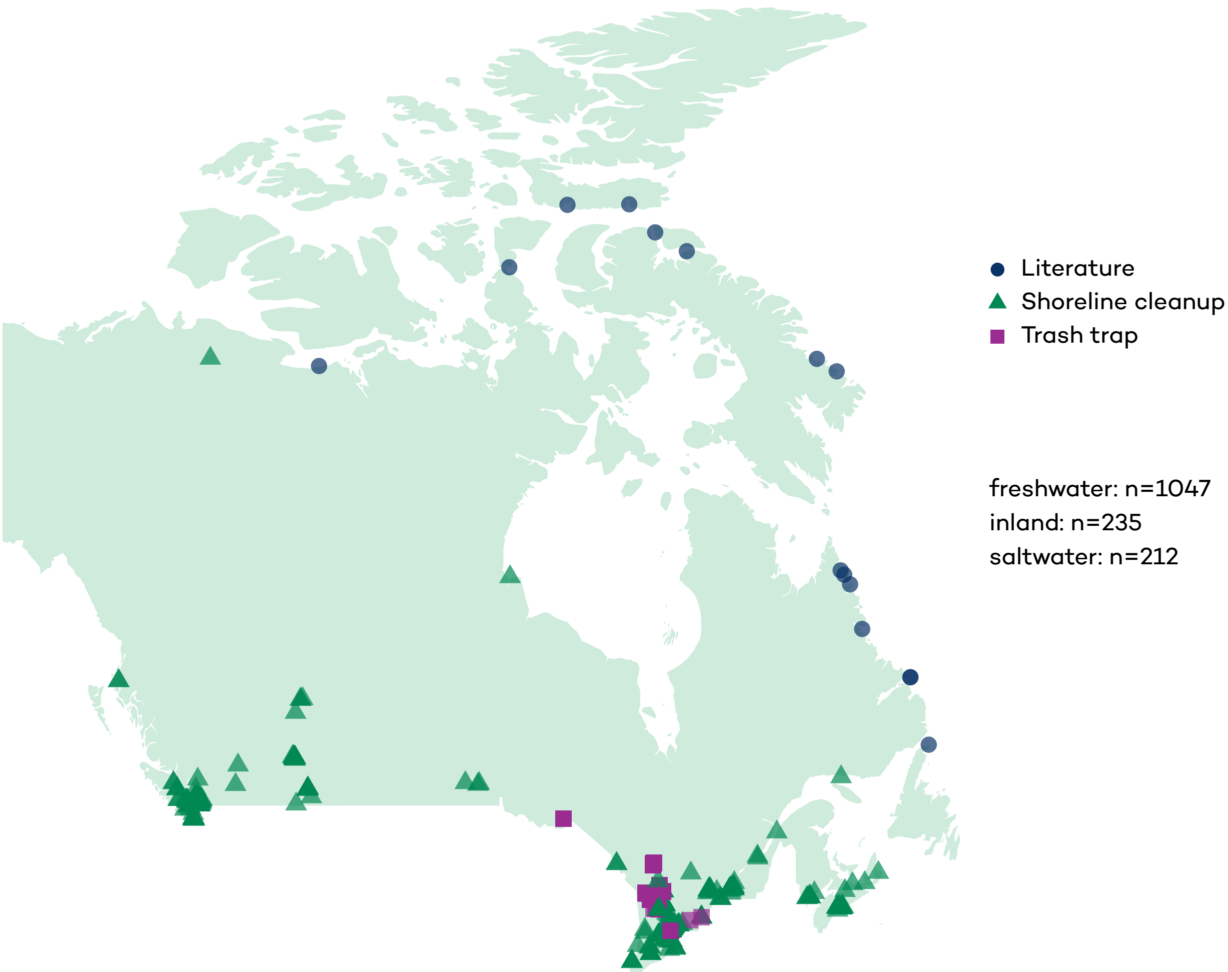
Cleanups where users did not report a unit of effort (e.g., metres surveyed, total area, or hours of operation) were excluded from the data set. Locations and habitats of cleanups were verified using ArcGIS Pro (Version: 3.1.0). Habitats were categorized as freshwater (e.g., lake beaches, riverside parks), marine (e.g., coastal beaches), or terrestrial (e.g., urban parks, city streets, rural areas). If there was a mismatch between the habitat reported by the user and the GPS coordinates, the coordinates were used to determine the correct location.

Trash item categories were standardized across all data sources based on the categories used in TIDES. Items were also grouped into broader categories based on the classification system described in Haney et al. (2025) (Table 2). For example, plastic food trays, cutlery, and drinking straws were grouped under "food-related" items. Additionally, data was classified into two main categories:

- single-use plastic (SUP) items (bottle caps, plastic bottles, cigarette butts, electronic cigarettes, foam food trays, lids for takeaway cups, takeaway cups, and tampon applicators)
- other macroplastic items (excluding SUPs).

We also estimated the total mass of SUPs by assigning a representative weight (g) to each item type. The combined original dataset contained 2,118 unique cleanups, surveys, and trash trap collections. After filtering, 1,494 data points remained: 656 shoreline cleanups, 15 surveys from the literature, and 823 trash trap entries (Figure 3).

Figure 3. Locations of sampling sites across Canada, including citizen science cleanups, trash traps, and literature-based surveys (n=1494)



Source: Authors' diagram created in ArcGIS Pro (V. 3.1.0) using data from Ocean Conservancy, 2024 and Mallory et al., 2021.

SUP Impacts on the Environment—EGS

As part of understanding the range of effects that macro- and microplastics in the environment can have on EGS across both terrestrial and freshwater systems, we first conducted a literature scan of existing studies linking plastic pollution to EGS losses. Based on this scan, we mapped the potential pathways through which plastic contamination may affect regulating, provisioning, and cultural ecosystem services.

To explore specific impacts quantitatively, we then applied results from a recent global meta-analysis and modelling study (Zhu et al., 2025a), which examines how microplastic pollution affects photosynthesis and primary productivity in agricultural soils, with downstream consequences for crop production. Using these findings, we developed a preliminary estimate of how increasing microplastic concentrations could affect productivity and the economic value of production for wheat and corn, two major crops in Canada.

We acknowledge that major sources of plastic contamination in agricultural soils are linked to specific agricultural operations, including practices of plastic mulching (Salama & Geyer, 2023), biosolids application derived from wastewater sludge that often contains high concentrations of textile fibres (Dal Pio Luogo & Cascini, 2025; Gies et al., 2018), and other farm-related plastic inputs. However, SUPs may also contribute to agricultural soil contamination as secondary microplastics through atmospheric deposition, runoff, and wastewater residuals, including specific items that frequently appear in wastewater systems (e.g., tampon applicators) as discussed in Section 3.1.

This assessment provides a starting point for discussion and highlights the need for further research to better quantify the contribution of SUPs to terrestrial macro- and microplastic contamination and resulting ecosystem service losses. Given the complexity of plastic pathways into the environment, diverse polymer compositions, management practices that influence the fate of plastics in soils and the aquatic environment, and interactions between chemical additives and soil biological processes, more Canada-specific monitoring and modelling are required to develop more precise estimates.

2.2 Description of Tool Creation

The Excel-based *Plastic Waste Cost Calculator* was developed with the intention of providing a practical, interactive interface for local authorities to calculate how much they spend on SUP management annually. The tool is designed to consider costs related to the residential sector, commercial and industrial sector, and wastewater sector and aggregate this information in a single location. The tool offers options to calculate costs related to overall plastics in the waste streams, or for individual SUPs (coffee cups, water bottles, etc.). For initial tool development, we used all data collected from our sample set of Canadian municipalities to determine what types of data made sense to include and how to categorize them. We then refined it using preliminary feedback from two municipalities. After their initial feedback was implemented, we did a second round of testing in which six municipalities tested the refined tool prototype and provided feedback. Based on their feedback, we refined the prototype further before constructing the final version.

The tool was designed to allow some flexibility for municipalities that cannot collect as much data on their waste stream. Our analysis demonstrated that there is variability in the type and resolution of data being collected by waste management authorities across Canada. Many local authorities do not have data on specific SUPs and may be missing data from entire waste streams that are privately managed (e.g., private commercial recycling). The tool can be used if, at a minimum, data is available for the weight and cost of at least one waste stream (e.g., residential garbage). Municipalities can then use more tool features if they have more data, like including multiple waste streams or examining costs related to specific SUP items. For many localities, there are multiple organizations involved in waste management that have their own data. The tool is designed for all these different actors to be able to aggregate their data together and therefore gain a more holistic view of the costs of plastic waste in their locality. The more different actors collaborate in using this aggregation tool, the more useful it becomes for cost tracking and informing policy.

3.0 Results

3.1 Solid Waste Management—Residential Stream Analysis

Our results demonstrated a wide variety of waste generated for the residential waste stream, mainly dependent on city size and population. As one would predict, smaller municipalities produce fewer kgs of waste than larger municipalities (Table 4). We also observed variation in costs between cities (Table 6). This could be partially explained by the fact that larger municipalities tend to have more complex waste management systems and are more likely to manage waste locally, whereas smaller municipalities are more likely to ship some waste out for processing. There can also be variation due to the relative remoteness of different communities. The average proportion of plastic waste in the garbage stream for the municipalities that measured it was 15%.

In the recycling stream, we observed similar patterns as in the garbage stream, with larger municipalities producing more waste (Table 4). The average value of plastic waste in the recycling stream for the municipalities that took that measurement was also 15%. The average per capita spending on managing the recycling stream annually for municipalities that disclosed this data was CAD 88.14 (2025 dollars).

Table 4. Total garbage and recycling collected in each municipality included in the study for the residential stream

City	Year of data collection	Population serviced by waste collection	Garbage collected in 1 year (kg)	Recycling collected in 1 year (kg)
City 1	2024	Small	1,463,000	424,000
City 2	2017	Small	7,286,700	600,000
City 3	2024	Small	12,674,590	984,000
City 4	2024	Small	11,614,000	3,212,000
City 5	2022	Medium	48,351,000	18,399,000
City 6	2023	Large	Not publicly available	Not publicly available
City 7	2024	Large	131,418,000	33,373,000
City 8	2024	Large	351,690,000	92,009,000

Note: Populations serviced by the system were estimated based on the types of households serviced in each municipality and their average sizes using Census 2021 data and adjusted to the year the data was collected. Large = over 500,000, Medium = between 50,000 and 500,000, Small = under 50,000.
Source: Authors.

Table 5. Total garbage and recycling produced per capita for each municipality included in the study for the residential stream

City	Population serviced by waste collection	Estimated garbage per capita in 1 year (kg)	Estimated recycling per capita in 1 year (kg)
City 1	Small	182.19	52.80
City 2	Small	586.03	48.25
City 3	Small	407.46	31.63
City 4	Small	307.70	85.11
City 5	Medium	152.33	57.97
City 6	Large	78.26	41.25
City 7	Large	252.30	64.07
City 8	Large	Not publicly available	Not publicly available

Note: Populations serviced by the system were estimated based on the types of households serviced in each municipality and their average sizes using Census 2021 data and adjusted to the year in which the data was collected. Large = over 500,000, Medium = between 50,000 and 500,000, Small = under 50,000

Source: Authors.

Table 6. Cost per capita and cost per kg of managing garbage and recycling for each municipality included in the study for the residential stream (values adjusted to 2025 CAD)

City	Population serviced by waste collection	Estimated annual garbage cost per capita, CAD	Estimated garbage cost per kg
City 1	Small	Not publicly available	1.11
City 2	Small	174.43	0.23
City 3	Small	43.42	0.11
City 4	Small	43.81	0.14
City 5	Medium	41.65	0.27
City 6	Large	89.17[a]	1.14[a]
City 7	Large	54.84	0.22
City 8	Large	Not publicly available	0.69

City	Population serviced by waste collection	Estimated annual garbage cost per capita, CAD	Estimated garbage cost per kg
Average	-	71.63	0.40
Median	-	43.81	0.23

[a] Cost value includes recycling too. Because of how waste is collected in this city, it cannot be separated out. Number is excluded from average listed.

Note: Populations serviced by the system were estimated based on the types of households serviced in each municipality and their average sizes using Census 2021 data and adjusted to the year in which the data was collected. Large = over 500,000, Medium = between 50,000 and 500,000, Small = under 50,000

Source: Authors.

The costs counted in this analysis for the above municipalities included only variable costs, not capital costs. These variable costs include things like waste pickup, transportation, and landfilling. It does not include costs like public education programs that are not directly linked to managing the waste itself, or costs like one-time repairs to machinery that would not be variable based on the amount of waste.

These results are relatively consistent with studies in other jurisdictions. For example, according to World Bank Data, the cost of general waste management in high-income countries is 0.328 USD/kg (World Bank, 2018), which falls within the middle of the cost range in our data set.

Table 7 illustrates the per capita weights of each SUP from our list for which data was available from our sample municipalities. The results have been anonymized for data privacy reasons. Of our list of SUPs, only hot cups, cold cups, bottles, vaping devices, and foam trays had data from at least one municipality. Cup lids, bottle caps, cigarettes, and tampon applicators all had no data available from any municipality in our case study list. Data was most common for hot cups, and least common for vaping devices. The per capita weights of hot cups were quite variable between municipalities, ranging from 0.002 kg all the way to 0.99 kg per capita. By contrast, we saw a smaller range with cold cups, from 0.17 kg to 0.53 kg per capita. This may be partly because not all municipalities had data available on cold cups. Plastic bottles also displayed a broader range value, from 0.28–4.22 kg per capita. Foam trays ranged from 0.05–1.02 kg per capita. For vaping devices, we received an estimate from only one municipality. To illustrate what these results would mean on a larger scale: if every person in Canada consumed the median number of hot cups found in our data every year, that would be 30,295,000 kg of hot cups every year. According to our costing data of median cost per kg for garbage management, that would amount to CAD ~7 million in management costs just for the garbage stream. For bottles, if we made the same assumption that every Canadian would consume the median number found in our sample, that would come to 27,390,000 kgs, costing CAD ~6.3 million per year for the garbage stream alone (using the median value for cost per kg in the garbage stream).

Table 7. Estimated weights of SUP items of interest found in the garbage stream of sampled cities per capita, per year, (kg)

City	Hot cups per capita in garbage	Cold cups per capita in garbage	Bottles per capita in garbage	Vaping devices per capita in garbage	Foam trays per capita in garbage
City 1	0.64	no data	no data	no data	no data
City 2	0.79	0.53	0.28	no data	0.15[a]
City 3	0.99	no data	0.71	no data	no data
City 4	0.67	0.17	0.61[b]	0.01[c]	1.02[d]
City 5	0.9	no data	no data	no data	0.05
City 6	0.002	no data	4.22	no data	no data
Average values	0.67	0.35	1.46	0.01	0.41
Median values	0.73	0.35	0.66	0.01	0.15

[a] Includes other foam packaging (clamshell, etc.).
[b] Includes bottles, containers, and caps and buckets > 5L.
[c] Includes vaping cartridges.
[d] Includes other foam packaging (clamshell, etc.).
Source: Authors.

Discussion of Anomaly Results

We found a large variation in how much money municipalities spend per kg on waste management (Table 7). Some of this variation follows definite patterns we would expect to see, such as larger cities with more complex management systems spending more. However, some of the variation could also arise from differences in accounting methods due to data availability. When municipalities report on their waste management spending, differences in how certain costs are categorized may lead to discrepancies in estimates.

Non-Residential Waste Streams

Data on the non-residential waste streams was generally less consistently collected compared to the municipally managed residential streams and has fewer waste audits publicly available. For the garbage stream, the average weight of total waste collected was 27,988,307.5 kg, or 322.42 kg per capita. The average per capita cost of this stream was CAD 178.95 (2025) for the municipalities that offered this information. The per capita value listed here is based on the total populations of the municipalities rather than the population serviced by the public municipal system, since all residents of a city contribute to the commercial waste stream either at home (for multi-unit buildings), at work, or in commercial spaces.

We did not receive permission to access data on the non-residential stream for specific SUPs. However, according to Statistics Canada (2024), roughly 60% of the total garbage stream consists of non-residential waste. If we assume the same ratio applies to hot cups in the garbage stream, our sample data would estimate that 45,442,500 kg of hot cups are produced annually in the non-residential garbage stream. This number is calculated by assuming that the 30,295,000 kg of hot cups found in the residential stream represent 40% of the total of the residential and non-residential streams combined. If, for illustrative purposes, we assumed that the costs were the same between the residential and non-residential streams, this would mean CAD 10,451,775 being spent on hot cups in the non-residential garbage stream annually.

The same assumptions and calculations could be applied to plastic bottles. This would give us an estimate of 41,085,000 kg of plastic bottles produced each year in the non-residential garbage stream. If, for illustrative purposes, we assumed the costs were the same across the residential and non-residential streams, this would mean CAD 9,449,550 would be spent on plastic bottles in the non-residential garbage stream annually.

3.2 Wastewater Management Survey Results

Our survey, Single-Use Plastics in Canada's Wastewater Systems, yielded 11 responses from different municipalities across Canada located in provinces of Manitoba, Ontario, Nova Scotia, New Brunswick, British Columbia, and Alberta. Nearly all survey respondents were able to provide anecdotal information on the prevalence of individual SUPs in their screenings, but only two were able to provide any data. From Victoria, which was the only respondent able to provide numeric figures, we learned that in 2024 and 2025, 1.4 million kg of screenings were collected at their site (which services ~400,000 people), with ~50% of that being plastic. This plastic includes many different types of items, but in one set of two wet wells over the course of a week in 2026, they found 12 tampon applicators, seven cigarette butts, and seven cotton swabs, among other various items (see Figure 4 for examples of items found in screening).

No municipalities were able to provide costing information for individual SUPs. Other than Victoria, none were able to provide quantitative data on plastics in screenings in general. Perhaps the most significant result from this survey was the reason for lack of data on SUPs in the wastewater system—multiple municipalities cited lack of incentives and difficulty as the reasons data has not been collected. In a wastewater system, all screenings are mixed together and consist of all screened items, not only plastic ones. All screenings are removed and disposed of together, ending up in landfills (often in a separate area). This makes it difficult to quantify how many individual items end up in the system, and nearly impossible to separate out costs since all screenings are disposed of together. While audits are technically possible, they would be expensive in terms of both time and money, so without direct incentives, they are unlikely to take place. One respondent noted anecdotally that many wastewater treatment plants may possess data they are unable to share externally due to concerns about public perception. This is particularly relevant for facilities with combined sewer systems, where certain events such as stormwater overflows could result in some contaminants being released into the environment. This may have also contributed to the lack of data we observed.

Figure 4. Sorting of screening

Source: Barry Orr, Capital Regional District.

We did receive some anecdotal survey responses where the respondents were able to identify which SUPs they see frequently, without quantifying them. The most commonly observed SUPs were single-use wipes (which were not part of our initial list), vaping cartridges, tampon applicators, and cigarette butts, all of which the respondents unanimously reported seeing on a weekly basis. Other commonly listed items that were not part of our initial list were sanitary pads, dental floss, and cotton swabs, which respondents reported seeing anywhere from once a month to every week. The prevalence of single-use wipes in wastewater was unanimously reported across respondents, and there is currently work being done by the International Water Services Flushability Group (2026) to address this issue by proposing a universal flushability standard that would create uniformity in which wipes are being labelled as flushable. Implementing a policy of this type would help address the problem of wipes ending up in wastewater screenings.

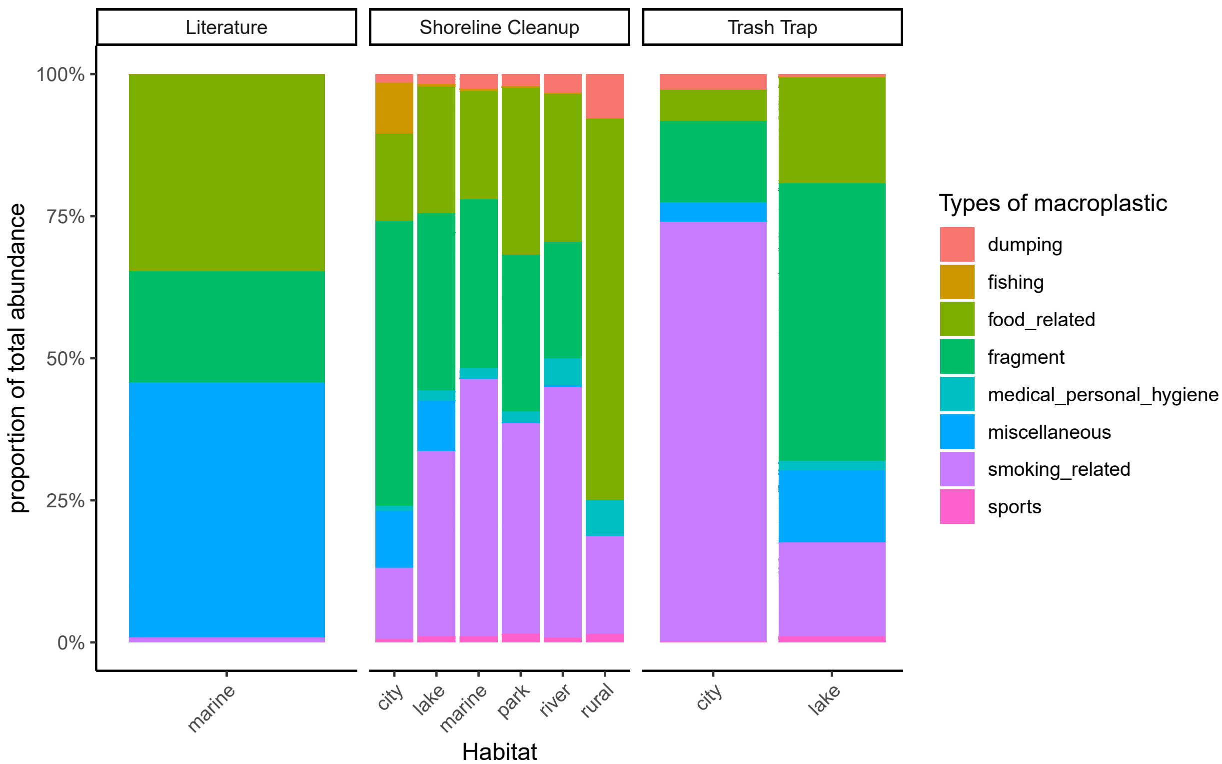
3.3 SUP Occurrences in the Environment—Litter

Abundance of Macroplastic and Single-Use Plastic Litter Across Canada

Macroplastic items in general and our select SUPs were found across diverse freshwater and marine habitats in Canada (Appendix C, Figure C1). Although data was categorized by general region in Canada, further spatial analyses could help explain variance in concentrations based on proximity to point sources (landfills, combined sewer overflows, etc.) and non-point sources (cities, harbours, etc.). Significant data gaps exist for the Northern Territories, with limited information for the Prairie and Atlantic regions (Appendix C, Figures C2–C4).

We observed a similar composition of macroplastic and SUP items across habitats and regions in Canada (Figure 5). The most prevalent items belonged to the smoking-related, food-related, and fragment categories, including cigarette butts, food wrappers, and nondescript plastic fragments (i.e., pieces of larger plastic items that have broken down). However, there are differences in the types of macroplastic observed between data sources (Figure 5). In the cleanup data, most items fall under the smoking-related (39%, by count), fragment (29%), and food-related (23%) categories. In the data from the literature, a larger proportion of debris is classified as miscellaneous (45%) and food-related (35%), likely due to differing reporting methods and a lack of standardized item classification. In trash traps, most macroplastic items belong to the smoking-related (53%) and fragment (27%) categories.

Figure 5. Composition of macroplastic across different habitats and data sources in Canada, grouped by product category (proportion of total abundance is based on count data)



Source: Authors' diagram based on data from Ocean Conservancy, 2024 and Mallory et al., 2021.

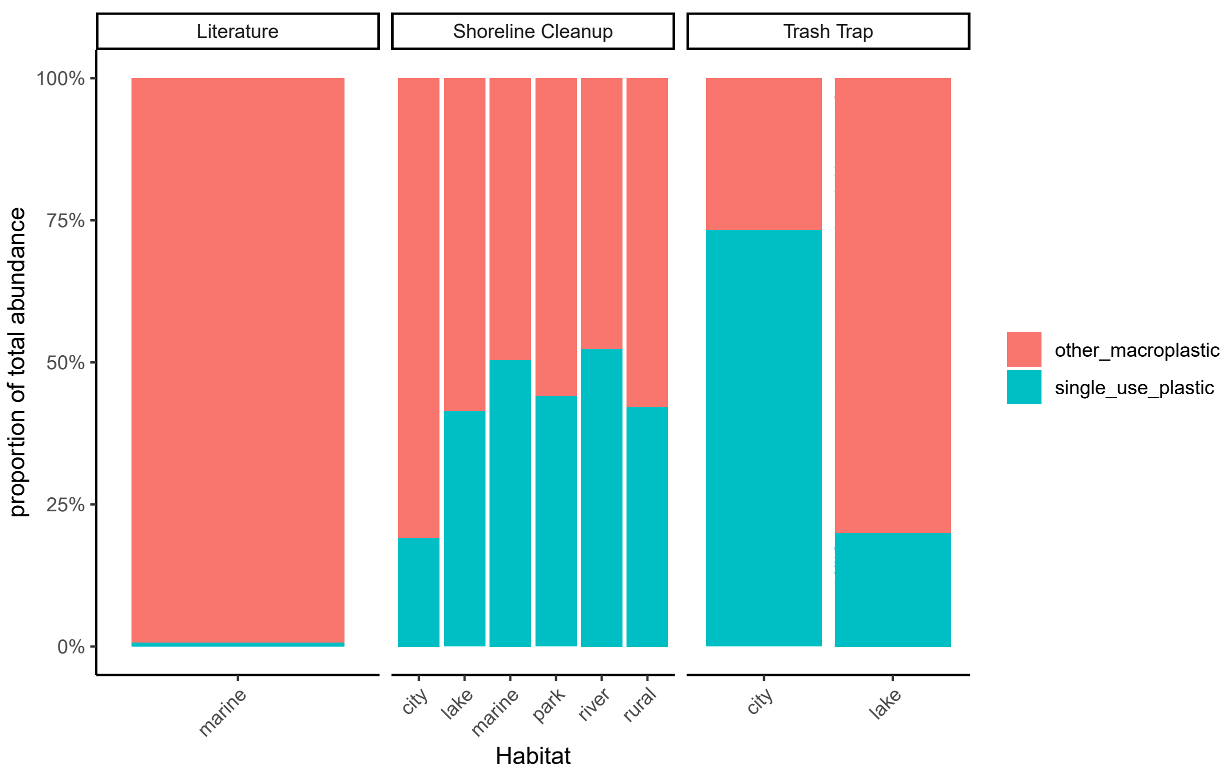
The overall homogeneity of macroplastic in the environment suggests that little to no environmental filtering or transport of items occurs between the emission of plastic into the environment and its collection through these cleanups or trash trap efforts. In other words, factors like size and density do not appear to influence transport or deposition of plastic in the habitats we studied. The similarity in inputs across regions also suggests that plastic pollution sources are broadly consistent across Canada.

Prevalence of SUP In the Environment by Count and Mass

The eight targeted SUP items comprised 46% of all macroplastic debris observed across Canadian habitats by count (Figure 5), with similar patterns seen across regions (Appendix C, Figure C6). However, when considering the total mass of all anthropogenic litter (including plastic and other materials like metal and wood) collected from cleanups and trash traps, the estimated mass of SUPs accounts for only 3% (Figure 6). These findings suggest that, although SUPs are very abundant in the environment by count, their small size and light nature mean they contribute relatively little to the overall mass of anthropogenic debris. Regardless, these results support the idea that policy targeting specific SUP items could significantly reduce the amount of plastic entering the natural environment in Canada.

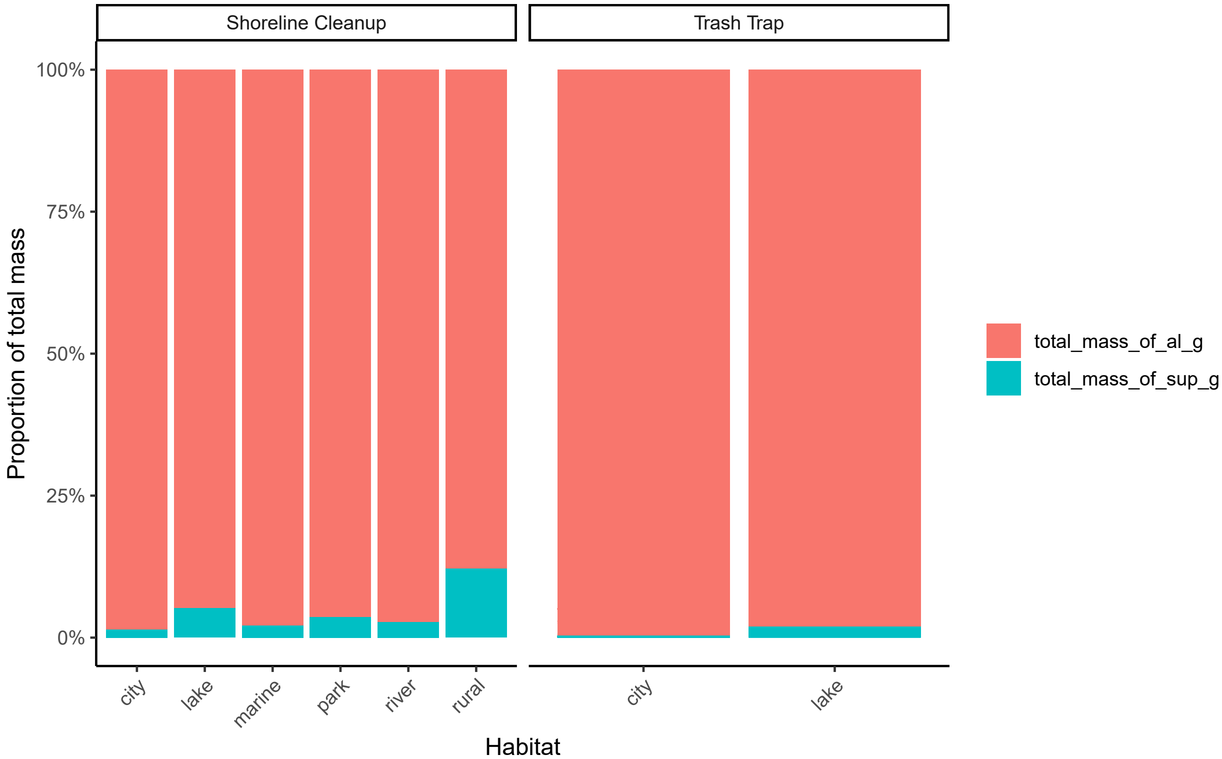
Cigarette butts are the most abundant plastic item by count, following global trends (Figure 6; Green et al., 2023; Ocean Conservancy, 2024). However, by mass, larger, denser items like plastic bottles and takeaway cups dominate, while cigarette butts represent a smaller fraction of the total weight (Figure 7). However, there are differences between the data sources. In the subset of the data set from the literature, all SUP items were cigarette butts, resulting in no shift when considering mass. A similar trend was observed in trash trap data from cities, where cigarette butts remained the dominant item by both count and mass.

Figure 6. Proportion of SUP items examined in the study and other macroplastics by count across different habitats and data sources in Canada



Source: Authors' diagram based on data from Ocean Conservancy, 2024 and Mallory et al., 2021.

Figure 7. Proportion of SUP items examined in the study and anthropogenic litter by mass (g) across different habitats and data sources in Canada

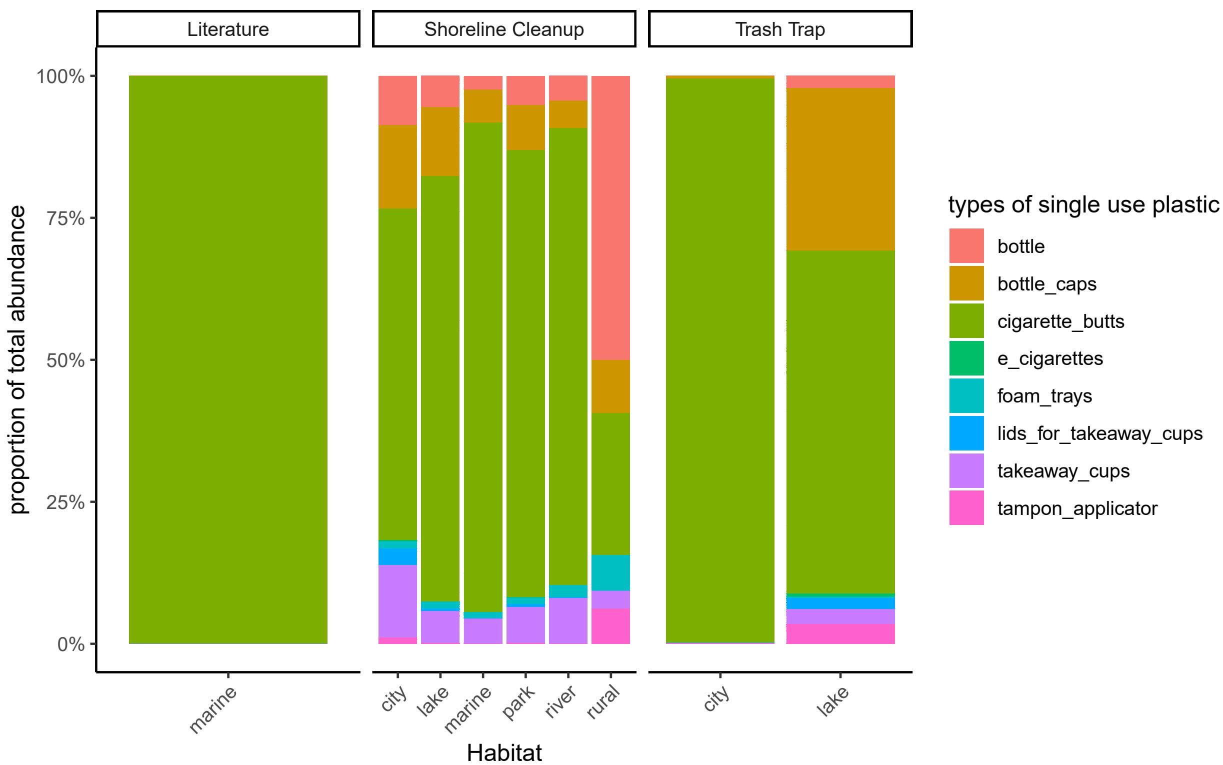


Note: Surveys from the literature were excluded, as they did not report mass.
Source: Authors' diagram based on data from Ocean Conservancy 2024 and Mallory et al. 2021.

Similar trends were observed in the litter audits conducted in our eight case study municipalities. Cigarette butts were the most prevalent by count across all municipalities that provided litter audit data, ranging from 185 in Halifax (Divert Nova Scotia, 2021) to 925 in Toronto (City of Toronto, 2022). The least commonly littered items in the case study cities were tampon applicators (found across all litter audits) and vaping devices, which only Halifax reported having found. Bottles, hot cups, and cold cups were found in all municipal waste audits provided, along with their lids and caps reported in smaller numbers. In all the audits, lids were found in smaller quantities than their corresponding beverage containers of all types. Foam trays were reportedly found in the litter audits from Edmonton, Halifax, and Toronto, but in small numbers (fewer than five found in all cases), while the other municipalities did not report finding foam trays in their litter audits.

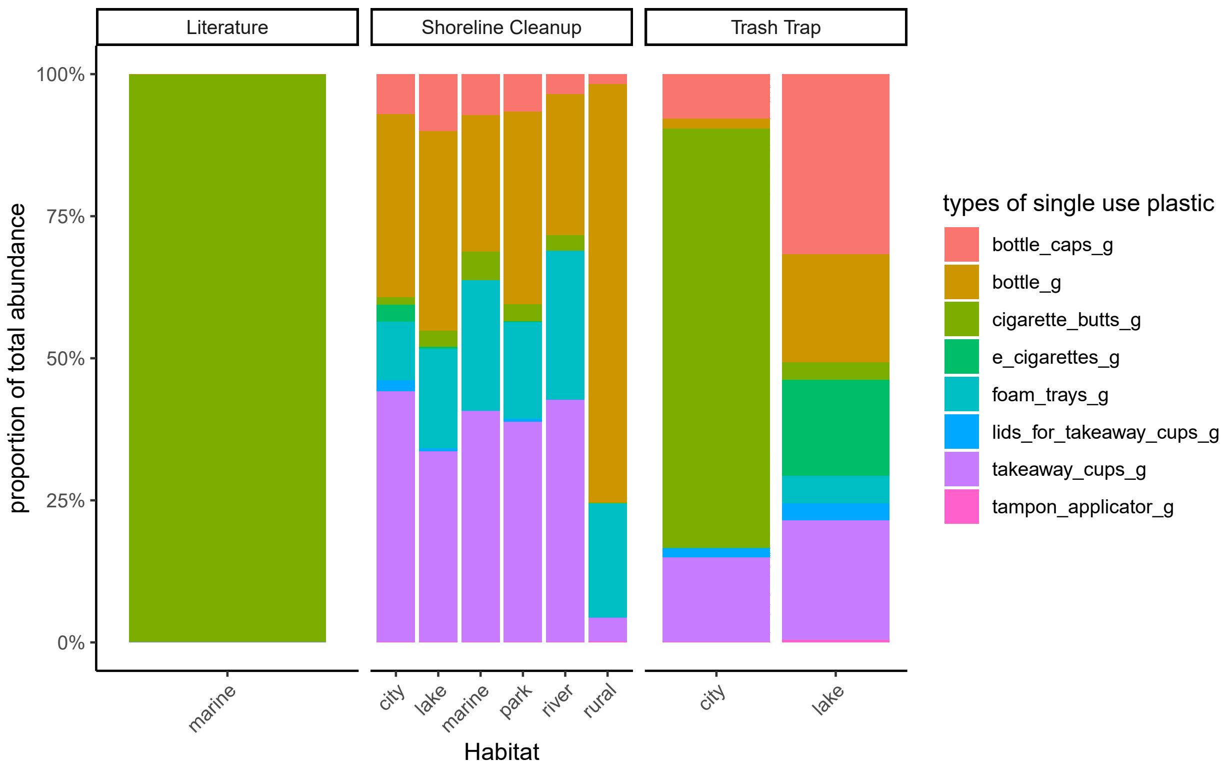
When considering the cost of litter cleanup, it is worth framing this in terms of opportunity cost of time rather than actual dollars spent. Litter cleanup is often left up to volunteers who self-organize and are not compensated for their efforts. Moreover, these cleanup efforts often measure their impact in ways that are different from how a paid employee would be compensated. For example, they may measure kilometres of shoreline cleaned rather than hours spent cleaning. However, some municipalities do pay workers to clean up litter, and from their cost data, we can begin to gain a scope of how much the work of litter cleanup is worth in dollar terms. Banff pays workers to clean up litter once per year, an effort costing approximately CAD 117,700.00 annually (Carla Bitz, personal communication, July 22, 2025). If a larger city took a similar initiative, we would expect it to cost more, scaling up along with increases in size and population of the city involved. However, even estimates like that from Banff must be taken as conservative because they do not encompass the full effort going into litter cleanup throughout the entire year.

Figure 8. Proportion of different SUP items by count across habitats and data sources in Canada



Source: Authors' diagram based on data from Ocean Conservancy, 2024 and Mallory et al., 2021.

Figure 9. Proportion of different SUP items by mass (g) across habitats and data sources in Canada



Source: Authors' diagram based on data from Ocean Conservancy, 2024 and Mallory et al., 2021.

3.4 Ecosystem Losses and Impacts

Sridharan et al. (2021, p. 1) note, microplastics impact terrestrial and aquatic ecosystem services: "MPs [microplastics] are perceived as a menace to the global ecosystems, but their possible impacts on the provisional, regulatory, and socio-economic ESs [ecosystem services] have not been extensively studied." A similar knowledge gap applies to macroplastics.

This knowledge gap is largely driven by the complexity of plastic fate and impacts across ecosystems. For example, the effects of microplastics on EGS depend on a wide range of interacting variables, including plastic type, size, shape, density, chemical toxicity, environmental context, and transport pathways through which plastics move across landscapes and food webs. For example, microplastics of different polymer types (e.g., PE, PET, PP, PS, PVC) and shapes (fibres, fragments, and spheres) can influence ecosystem functions differently, and their impacts are further complicated by "complex interdependencies among the ecosystem services induced by MPs application" (Yan et al., 2024). The following provides an overview of the evidence based on linkages between plastic contamination and EGS, drawing on findings from recent studies.

Mapping the Impacts of SUP—Microplastics and Macroplastics—on EGS

Macro and microplastic pollution (including originating from SUPs) has the potential to impact several EGS; however, more research is needed to fully understand, substantiate, and contextualize these effects. Here, we highlight potential impacts based on existing evidence, including some of the impact pathways from plastic contaminants to EGS value loss. Ecosystem services are categorized according to the framework outlined in the *System of Environmental-Economic Accounting: Ecosystem Accounting* (United Nations et al., 2024), representing material, regulating, and nonmaterial benefits from the natural environment to humans.

Provisioning Services

> "Provisioning services are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems" (United Nations et al., 2024, p. 145).

Macroplastic can threaten clean water by leaching toxic chemicals, either sorbed to plastic from the environment or added during production, such as nicotine, heavy metals, polycyclic aromatic hydrocarbons, and flame retardants (Dobaradaran et al., 2020; Gao et al., 2023; Green et al., 2014; Mohammadi et al., 2024). These pollutants may degrade water quality in natural ecosystems, groundwater recharge zones, and recreational areas. They may also affect food provision by impacting fish populations of commercially important species like the common dolphinfish (Menezes et al., 2019). However, more research is required to better understand the population-level effects of macroplastics on commercially or culturally important fish species in Canada. Species of birds and marine mammals affected may also lead to issues of food provision for Northern communities who rely on them for country food (Ratelle et al., 2021).

According to Sridharan et al. (2021), microplastics can appear in a wide variety of natural consumable goods, including potable water, fruits, vegetables, honey, sea salt, and seafood, with consequences to human health and people's economic contributions (through absenteeism, reduced performance, and health care costs) (Savchuk, 2025). Specific studies have identified high concentrations of microplastics in commercially processed fishmeal and the tissues of at least 56 edible fish species (Thiele et al., 2021). Microplastics have even been found in drinking water samples meant for direct human consumption (Coffin et al., 2022).

Furthermore, microplastics can reduce agricultural productivity by altering the natural structure and pH of soil, which leads to decreased biomass and lower yields for economically vital crops such as rice, wheat, and barley (Deng et al., 2024; Astner et al., 2023; Vox et al., 2026; Sridharan et al., 2021). Beyond direct food contamination, plastic debris in water bodies can cause a significant negative impact on aquatic animals and could put economic strain on fisheries (Gall & Thompson, 2015; Thornton Hampton et al., 2022).

Regulating and Maintenance Services

> "Regulating and maintenance services are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles and thereby maintain environmental conditions beneficial to individuals and society" (United Nations et al., 2024, p. 145).

Macroplastics may impair regulating services. In the terrestrial environment, macroplastics can hold water or clog stormwater drains, creating breeding habitats for disease vectors such as mosquitoes (Maquart et al., 2022). This is particularly concerning in urban areas, where macroplastics may provide significant habitat for container-breeding mosquitoes and increase the chances of human–mosquito interactions (Trewin et al., 2013). Macroplastic may also interfere with pollination; for example, flowers from riparian vegetation can be smothered by debris, reducing plastic-insect interactions and inhibiting flower growth (Gallitelli & Scalici, 2023).

In turn, microplastics and their leachates interfere with essential nutrient cycles, specifically nitrogen and carbon cycling, in both terrestrial and aquatic sediments (Salam et al., 2023; Sridharan et al., 2021). The "plastisphere" also acts as a mobile home for invasive, virulent, and antibiotic-resistant microbes, facilitating the horizontal transfer of resistant genes from wastewater into the natural environment (Ma et al., 2020; Yang et al., 2020). These pollutants also target ecosystem engineers, such as earthworms and springtails, disrupting their metabolic rates, gut microflora, and soil-tilling activities (Klimasz & Grobelak, 2025), which are critical for soil formation and decomposition—a regulating EGS.

Cultural Services

> "Cultural services are the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contribute to a range of cultural benefits" (United Nations et al., 2024, p. 145).

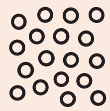
Macroplastic pollution negatively affects recreational and tourism experiences. In Orange County, USA, beachgoers avoided areas with high debris density, leading to reduced visits and decreased economic spending in surrounding communities (Leggett et al., 2014). In South Wales, UK, littered items negatively influenced the mood and well-being of beachgoers (Tudor & Williams, 2003). Macroplastic can also impact tourism revenue; for example, following a major rain event, tourism declined on Geoje Island, South Korea, due to macroplastic accumulation (Jang et al., 2014). Conversely, community-led cleanups can enhance a sense of place and foster community engagement (Battisti & Gippoliti, 2019).

Microplastics also degrade cultural services. One of the most subtle but dangerous impacts is the thermal alteration of habitats; microplastics in beach sand can increase heat retention, which may bias the temperature-dependent sex ratios of nesting sea turtles and jeopardize their future reproductive success (Carter et al., 2018; Nelms et al., 2016). These contaminants have also been detected in the diets of flagship and culturally significant species, including Asian elephants, baleen whales, and dolphins (Katlam et al., 2022; Kahane-Rapport et al., 2022; Novillo et al., 2020). If contamination contributes to population-level impacts, it could reduce ecotourism and wildlife-viewing activities, with associated economic losses.

The impact pathways from plastic contaminants to EGS value loss are summarized in Figure 10.

Figure 10. Mapping of some of the impact pathways from plastic contaminants to EGS value loss

Contaminants


Microplastics


Macroplastics

Biological and ecological processes affected

Plant productivity and bio impacts
- Reduced floral and faunal biomass
- Disruption of photosynthesis & carbon dioxide capture
- Reduced plant productivity

Soil functioning
- Alteration of nitrogen & nutrient cycling
- Soil fertility reduced
- Microbial biodiversity reduced

Biological disturbance
- Pollination interference
- Habitat smothering affecting carbon flow
- Pathogen transport & antibiotic resistance

EGS impact

Provisioning
- Food security
- Fisheries productivity
- Freshwater supply
- Reduced biomass production

Regulating
- Climate regulation (reduced sequestration)
- Disease regulation
- Water purification

Cultural
- Nature-based tourism
- Aesthetic value
- Mental health
- Heritage species threats

Source: Authors.

Estimating Ecosystem Losses From Microplastics in Canada (Crop Production)

Microplastic contamination is a significant concern for agricultural soils and production, specifically through its disruptive effects on soil structure, soil permeability, water and nutrient absorption, and microbial communities, posing risks to plant growth (Astner et al., 2023; Deng et al., 2024; Vox et al., 2026). Agricultural soils receive substantial inputs of plastics from diverse sources: synthetic microfibres from clothing and other microplastic fragments that enter agricultural land through biosolids derived from treated sludge used as fertilizer, inputs from car tire wear, from plastic tools used in everyday farming operations and through effluent irrigation (Cosier, 2021; Deng et al., 2024; Gies et al., 2018). It is estimated that 61,754 metric tonnes of agricultural plastic waste are generated annually across Canada (Cleanfarms, 2021).

A recent multi ecosystem meta-analysis and modelling study reviewed how agricultural soils respond to increasing levels of microplastic pollution through its effects on photosynthesis (Zhu et al., 2025a). The study analyzed a total of 3,286 observations compiled from 157 studies across terrestrial, marine, and freshwater ecosystems. In addition to the meta-analysis, Zhu et al. (2025a) constructed a machine learning model using microplastic pollution levels reported in the literature. The meta-analysis revealed that microplastic exposure "leads to a global reduction in photosynthesis of 7.05 to 12.12% in terrestrial plants, marine algae, and freshwater algae" (p. 1). The study also found that, when considered together, microplastic size, exposure concentration, and exposure duration have significant positive relationships with the effect sizes of total chlorophyll or chlorophyll a. This points to a three-dimensional structure of microplastic induced inhibition of photosynthesis.

This work provides a useful starting point for estimating EGS responses to plastic pollution in terrestrial ecosystems, which is particularly relevant given the critical role of crop production in the Canadian economy and food security, both domestically and internationally. In translating this approach to the Canadian context, it is important, however, to consider the following caveats:

Study Sites in Meta-Analysis

North American studies make up only 1.79% of the database used in the meta-analysis for impacts on terrestrial ecosystems, and just 0.06% for freshwater ecosystems. This is an important consideration when assessing the transferability of the resulting effect sizes and the assumptions about microplastic concentrations in soils that drive the modelled reductions. The majority of study sites in the literature were located in Asia.

Microplastic Concentration in Agricultural Soils in Canada

A study in Southern Ontario detected microplastics in biosolid-amended agricultural soils at an average concentration of 3.43 ± 0.74 mg microplastics per kg^{-1} (equivalent to 0.000343% w/w), based on samples collected from seven agricultural fields (Walker & Aherne, 2024). The meta-analysis database in Zhu et al. (2025b) indicates that 39.25% of observations for terrestrial ecosystems fall within reported exposure concentrations ≤1% (w/w), while 60.75% exceed 1% (w/w). This suggests that a substantial proportion of the exposure scenarios considered in the analysis occur at concentrations higher than those observed in biosolid-amended agricultural soils in Southern Ontario (3.43 ± 0.74 mg/kg; Walker & Aherne, 2024), although the lower concentration range may partially overlap.

Projected Production Losses for Corn and Wheat in Canada

Zhu et al. (2025) applied the meta-analysis-derived effect size within a conceptual framework using the Soil Canopy Observation of Photosynthesis and Energy fluxes (SCOPE) model to estimate global crop production losses of wheat, maize, and rice. The SCOPE model describes radiative transfer processes and exchanges of energy fluxes, carbon, and water among the soil, vegetation, and the atmosphere (Prikaziuk et al., 2023). It has been extensively employed in simulating gross primary productivity (GPP) and is used in the study to translate reduced photosynthesis into decreased primary productivity. Crop production losses were obtained by simulating GPP without microplastic exposure and with microplastic exposure, based on the premise that the loss percentage of crop production is equal to that of GPP.

Findings Specific to North America

- wheat: Expected losses range from 4.28 to 14.02 million tonnes (MT), representing approximately 5.4% to 17.7% of the average annual production of 79.22 MT (2019–2021).
- maize (corn): Expected losses range from 15.69 to 52.26 MT, representing approximately 4.2% to 13.9% of the average annual production of 376.29 MT (2019–2021).

Because the study did not find a significant effect of study site location on photosynthetic responses, the reported global inhibition percentages can be provisionally applied to estimate potential impacts for Canada, assuming other parameters in the SCOPE model remain unaffected. However, the availability of more accurate, region-specific microplastic contamination data for Canada would help address variability in the effect sizes on total chlorophyll content and allow this production impact estimate to be refined into a more precise range (Fei Dang, personal communication, February 6, 2026).

We have estimated the percentage of crop production losses for North America and applied these to the Canadian agricultural sector using 2022–2025 production averages and 2025/26 price projections, highlighting significant economic risks (Table 8). Microplastic pollution poses a tangible and quantifiable threat to Canadian agriculture, with the estimated value-at-risk ranging from CAD 0.5 to CAD 2.16 billion annually. The resulting yield reductions represent additional losses relative to present-day conditions, which may already include microplastic exposure, providing a clear illustration of the potential consequences of continued microplastic contamination (Fei Dang, personal communication, February 6, 2026).

Attribution to SUPs

SUPs can enter agricultural soils as secondary microplastics, primarily through the application of biosolids derived from wastewater and sludge treatment processes. In Canada, single-use items, particularly tampon applicators and wipes, are commonly found in wastewater management systems. Atmospheric deposition may also contribute SUP particles, although precise quantifications are not currently available. There are also other significant sources of microplastics in agricultural soils that are highly relevant for Canada, such as textile fibres from biosolids, tire abrasion, and the degradation of agricultural-specific plastics.

Taking a conservative approach and assuming only 1% SUP contribution to microplastic contamination in Canada's agricultural soils, the resulting impact on crop yields at the concentrations reported in global studies by Zhu et al. (2025a) could be substantial, amounting to millions of dollars in economic value of lost yields (see Table 8).

Table 8. Estimated microplastic and SUP–induced production losses (Canada)

	Corn for grain	Wheat, durum	Wheat, spring & winter (remaining)	Total
4-year average production (2022–2025) (tonnes)[a]	14,917,024	5,888,150	30,158,357	
Price per tonne (2025/26, CAD)[b]	$220	$280	$265	
Total production value (CAD)	$3,281,745,280	$1,648,682,070	$7,991,964,539	$12,922,391,889
Microplastic induced loss (%)—low[c]	4.2%	5.4%	5.4%	
Microplastic induced loss (%)—high[c]	13.9%	17.7%	17.7%	
Estimated microplastic-induced value loss (CAD)—low	$136,837,502	$89,072,952	$431,779,957	$657,690,411
Estimated microplastic induced value loss (CAD)—high	$455,776,152	$291,776,352	$1,414,382,010	$2,161,934,514

	Corn for grain	Wheat, durum	Wheat, spring & winter (remaining)	Total
1% value loss (CAD)—low (illustrative SUP induced)	**$1,368,375**	**$890,730**	**$4,317,800**	**$6,576,904**
1% value loss (CAD)—high (illustrative SUP induced)	**$4,557,762**	**$2,917,764**	**$14,143,820**	**$21,619,345**

[a] Statistics Canada, 2026.
[b] Agriculture and Agri-Food Canada, 2025.
[c] Based on Zhu et al., 2025b.
Source: Authors.

Discussion

The pathways leading to EGS impacts from macro- and microplastics are inherently complex and depend on numerous environmental factors. The fate of plastics in agricultural soils is influenced by their type, the pathways by which they enter soils, and farm management practices (e.g., as tillage vs. no-tillage), which affect how plastics interact with microbial communities and are distributed within the heterogeneous soil environment. Variability in amendment practices further complicates this picture.

Nevertheless, it is well established that microplastic pollution can significantly reduce the yield and economic value of wheat and corn production. These estimated values illustrate the fact that agricultural production and food security are at stake if plastic pollution, including SUP, is not reduced. However, it is important to note that the specific pathways by which plastics affect soil processes remain the subject of ongoing study and depend on multiple factors, such as time in the environment, particle size, and concentration, each contributing uniquely to biological and environmental effects.

Another important note is that even when these costs are borne by agricultural producers, some sources of plastic pollution originate from environments beyond the agricultural ecosystems, like SUPs generated in urban settings. This creates, in part, a mismatch between the source of pollution and those bearing the economic burden of that pollution and its associated cleanup costs.

4.0 Discussion and Summary of Results

Based on our analysis, Canadian municipalities are spending millions of dollars per year on the management of plastic waste across multiple waste streams. The key results of our analysis for specific SUP items are summarized in the cards displayed in Figure 11.

Our results demonstrate that by weight, plastics make up approximately 15% of both the garbage and recycling streams. Part of our analysis also involved tracking specific SUPs to determine where they end up in the waste management system and the associated costs. This analysis yielded some surprising results. Vaping devices and cartridges are being undertracked across all regions. We were unable to find waste audit data regarding vaping products from nearly all municipalities analyzed. This may be partially attributed to the relative newness of these products on the market. We also found no municipalities from our subset tracking vaping cartridges in the major waste streams. However, wastewater treatment facilities responding to our survey frequently reported finding these disposable cartridges in wastewater screenings. We heard from one municipality that at least some of these cartridges are entering the wastewater stream through secondary schools, implying use by students. The wastewater facilities that reported this were not able to provide specific cost breakdowns for how much vaping devices specifically cost them each year, but were able to identify that there are always costs associated with the removal of plastics from the system. This is an area that could be better tracked to gain a fuller understanding of how vaping products are interacting with Canadian waste management systems. A similar pattern was found with tampon applicators, which were consistently undertracked. However, all wastewater survey respondents reported regularly finding tampon applicators in screenings. At the same time, they were not able to provide quantitative estimates for either amount or cost.

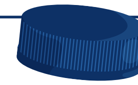
Other specific SUPs were better tracked across municipalities, particularly ones associated with beverage consumption, like cups and bottles. However, the way in which data is typically collected on these items differs from how data is collected on the waste streams in general, which can complicate analysis: while the overall waste streams and their costs are measured using weight, data regarding specific SUPs is often collected as count data. This means that to estimate the associated costs with these SUPs, the weight must be estimated based on the average weight of those items. However, more accurate cost estimates could be calculated if data on specific SUPs was consistently measured as weight in addition to count. This may be particularly relevant in cases where EPR schemes require accurate cost data to improve efficiency. We were not able to locate any specific tracking data on cup lids or bottle caps. For foam trays, we found minimal tracking data, but it was not tracked consistently enough to draw reliable conclusions.

Figure 11. Summary of key results for specific SUPs

Plastic bottles

Plastic bottles are one of the most commonly tracked SUPs across municipalities due to their high recycling potential, but they are often not recycled.

In shoreline cleanups, plastic bottles are one of the most commonly found litter items, especially in rural areas. If every Canadian disposed of the median number of bottles found in our sample, it would cost **~CAD 6.3 million[a] per year in the residential garbage stream alone.**



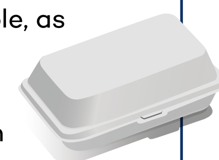
Bottle caps

Bottle caps are less consistently recyclable than bottles because they are made from different materials and there are varying recycling capacities between municipalities. Bottle caps are also less commonly tracked in waste audits than the bottles they belong to. As litter, they are especially common in rural areas and alongside lakes.

Cold cups and lids

Disposable cold cups and lids pose a challenge for tracking because of their large variation in shape, size, and weight.

Even though cold cups are nearly all recyclable, they often get disposed of in garbage or as litter. In shoreline cleanups, these cups are one of the most commonly found litter items by weight.



Foam trays

Foam trays are common in the food industry but are rarely recyclable, as are other foam-based SUPs.

Foam trays are often found in high quantities as fragments in litter because of their tendency to break into small pieces, including microplastics in the environment.

In shoreline cleanups, foam trays and their fragments are consistently common across all environment types. By mass, they are one of the top three litter items found in trash traps.

Hot cups and lids

A typical disposable hot cup is only composed of 5% plastic. The rest of the cup is made from paper or cardboard materials.

If every Canadian disposed of the median number of hot cups found in our sample, it would cost **~CAD 7 million[a] per year in the residential garbage stream alone.**

Cigarette butts

Cigarette butts are the most commonly littered item in Canada by count across jurisdictions. In cities, they account for over 95% of litter in trash traps by count.

Over 5,000 tons of cigarette butt waste is produced annually in Canada (Physicians for a Smoke-Free Canada, 2020).

Vaping devices

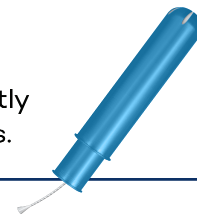
Vaping devices pose a fire hazard when disposed of because they contain batteries.

Vaping cartridges frequently end up in wastewater and have to be screened out in treatment plants. Some of these cartridges enter the wastewater stream through schools, indicating use by students.

Tampon applicators

Tampon applicators should only be disposed of in the garbage, but they are often found in wastewater screenings.

Tampon applicators are an undertracked SUP, frequently excluded from waste audits.



[a] Based on the median cost value derived from the sample of six Canadian municipalities.

Source: Authors.

4.1 Caveats

There are a few caveats that should be considered when interpreting the results of this study. One of these is that not all municipalities surveyed had data on specific SUPs of interest. This means that our estimates could have been strengthened by having a larger sample size. This is also true in application to our results from the non-residential waste streams. Some municipalities were also not able to disclose some data regarding their non-residential waste streams due to the private management of those streams. The small sample size for these values should be considered when interpreting our results.

Another caveat to consider is that SUPs have a high volume-to-weight ratio compared to other disposable materials, such as glass or paper, that end up in the same waste streams. According to one municipality interviewed as part of the present study, plastics can make up 16.2% of the audited weight but represent 55.2% of the volume consumed. Typically, amounts of waste in each stream are measured according to weight rather than volume. This means that the amount of plastic waste being measured can end up being under-reported because it weighs so little for the volume of waste involved. In terms of cost, this would also mean that plastics account for a greater share of the costs of managing both the garbage and recycling waste streams than our data suggests. In this sense, our estimates of the cost for the plastic proportion of the waste stream should be considered conservative. This is a particularly important point to consider for any users of our *Plastic Waste Cost Calculator*, which was developed using weight data.

5.0 Conclusion and Recommendations

SUP waste costs Canadian municipalities millions of dollars each year, but due to undertracking of certain SUPs, it is difficult to attribute accurate cost estimates to specific SUPs. While certain SUP items are recyclable (e.g., bottles, cups), they are frequently disposed of incorrectly, including in garbage or littered. Specific SUPs that are tracked the least across municipal waste streams include vaping devices, tampon applicators, and foam trays. Other SUP types, like hot cups, cold cups, and bottles, are being better tracked, but there could still be improvements in the frequency of waste audits for these items. Cigarettes and bottle caps are well tracked in litter audits but poorly tracked within formal waste management systems.

5.1 Main Findings and Recommendations for Tracking SUP Waste in Canada

1. Improve tracking of SUP waste

Our study clearly indicates that municipalities are currently facing and will continue to see increasing costs associated with SUPs. To understand the specific costs and find ways to address these, including in partnership with the private sector and other levels of government, we need to first improve tracking of SUP waste in Canada. For this, the number of waste audits in the garbage, recycling, and wastewater streams would all need to be increased.

However, waste audits are resource-intensive and typically require dedicated funding that most small and mid-sized municipalities do not have access to. Furthermore, smaller and more remote municipalities face additional barriers related to staffing capacity, contractor availability, and the costs of shipping materials for specialized sorting and analysis. Therefore, we recommend providing incentives, including funding, for more waste audits in the garbage, recycling, and wastewater streams to help create a better understanding of specific SUPs and inform ways to reduce their prevalence. One way to do this would be to have dedicated waste audit funding available from the provincial, territorial, or federal governments, which also considers the specific needs and circumstances of remote municipalities.

As EPR programs are rolled out throughout the country, we may see improvements in the tracking of individual SUPs. However, EPR primarily drives tracking and reporting by material type rather than by the specific item from which the material originated, especially in relation to recycling. Recycling facilities sell recovered materials, not SUPs, and they are not currently designed to track individual SUP items.

2. Implement new methods for measuring waste streams and waste audits that focus on volumetric measurements

An additional note in relation to this recommendation relates to our finding that waste management tracking currently relies almost exclusively on weight. However, plastic items have a very high volume to weight ratio. Collection vehicles fill by volume, and lightweight plastics, such as foam trays, cups, and lids, quickly occupy truck capacity, increasing collection frequency and fuel costs. Implementing new methods for measuring waste streams and waste audits that focus on volumetric measurements would lead to a more accurate understanding of how much SUPs truly cost management systems.

3. Establish standard practices for SUP-related data collection methods and item categories across communities

Establishing standard practices for SUP-related data collection methods and item categories across communities would be a significant step forward in generating valuable data sets. The Excel-based tool developed as part of this project can contribute toward this goal.

4. Create a universal flushability standard

Based on the finding that wet wipes are a prevalent type of SUP appearing in wastewater screenings, we also recommend the creation of a universal flushability standard—ideally at the international level, or at minimum nationally—like the one recommended by the International Water Services Flushability Working Group, to ensure uniform standards are applied across the industry and address the extra cost burden faced by wastewater systems.

5.2 Recommendations Related to Evaluating Abundance Data of Plastic Items From Community Cleanups

It is difficult to quantify and compare sampling effort across community cleanups, limiting the comparability of macroplastic counts across habitats and data sources. Factors such as the number of participants, cleanup duration, and effort likely affect reported macroplastic counts. Area estimates are also often missing or unreliable. Differences in units across data sources limit direct comparisons. According to our results, cigarette butts are the most common SUP found in trash traps by count near lakes, while beverage containers (cups and bottles combined) are the most common SUP by weight. However, in urban areas, cigarette butts were the most common SUP found in terms of both count and weight, demonstrating the prevalence of this type of litter in cities. In rural areas, plastic bottles were much more prevalent as litter compared to other types of environments examined in this study.

Harmonizing data collection methods and item categories across community cleanups would be a significant step forward in generating valuable datasets. It would also be a useful addition to the TIDES database to have a feature allowing users to estimate the total area cleaned by inputting an estimate or drawing a polygon on an interactive map. The prevalence of community cleanups as a means of removing litter makes them a key data source for mismanaged macroplastics in the environment. Providing guidance on standardized data collection methods would improve the usefulness of this data for policy-makers.

5.3 Recommendations on the Use and Further Development of the Excel-Based *Plastic Waste Cost Calculator*

A plastic waste cost calculator tool was developed, accessible here.

Local authorities can use this tool as a framework to aggregate data across multiple organizations responsible for waste management in their locality. For example, if different organizations handle recycling versus garbage, or manage multi-unit residences versus single-family homes, they can consolidate their data using this tool. This allows local authorities to gain a more holistic view of the total costs of plastic waste management in their area. It is worth noting that when aggregating information, data access and sharing between entities—especially private waste collectors or managers—must be resolved on a case-by-case basis through agreements, assumptions, or the use of proxy data.

Similarly, provincial, federal, or regional authorities could use this Excel-based tool to track and aggregate plastic waste quantities and costs across Canadian municipalities on a larger scale, supporting policy advocacy related to plastic waste management. It is important that existing data from provincial and federal sources be analyzed first before requiring municipalities to complete new surveys. Harmonizing data collection can reduce the reporting burden on local authorities by minimizing duplicate requests and preventing the need to submit similar information multiple times to different agencies.

Currently, the tool utilizes weight-based allocation for cost calculations. However, SUPs are typically high-volume but lightweight materials. We wish to draw attention to this design element and recommend that future iterations of the tool incorporate volumetric measurements and adjustments. In doing so, municipal waste management departments—particularly operational staff—should be engaged to help develop appropriate volume conversion factors, such as those based on material densities or other practical proxies for volume.

5.4 Observations and Recommendations on Estimating EGS Losses From SUP Waste in Canada

The main challenges in understanding EGS impacts lie both in the difficulty of attributing environmental effects to specific products, given their multiple waste pathways, and in mapping the scientific linkages between micro- and macroplastics and various biological and ecological processes, including the identification of tipping points, which is needed to assess changes in ecosystem conditions and impacts on human uses, such as EGS losses and their associated economic value.

To address these challenges, it is first critical to improve tracking of plastic waste, including its chemical composition at both macro and micro levels, across Canadian solid waste management and wastewater systems, as well as in litter, soils, and aquatic environments. This should be coupled with comprehensive information on plastic items on the market to better allocate environmental impacts to specific products. While such tracking is critical, a degree of scientific uncertainty will remain when attributing particular plastic items in waste and litter to precise levels of environmental contamination, particularly microplastic contamination. Data collection should therefore aim to reduce these gaps while acknowledging the complexity of linking specific products to their impacts in natural systems.

Second, scientific studies should be conducted to understand risk (through dose-response studies) and determine the mechanisms of effects of macro and microplastic effects on a full range of biological processes in terrestrial and freshwater environments. Research should also prioritize the effects of chemical additives to more fully evaluate effects on ecosystems and, therefore, EGS losses.

Additionally, research should consider human health alongside ecological impacts, accounting for disparities in how plastic pollution affects different populations. Further research may also examine risks to other unique values attributed to ecosystems—for instance, the cultural ties of Indigenous Peoples to key species and water resources—to ensure a more comprehensive understanding of EGS losses from plastic pollution.

References

180Smoke. (2026). *Disposable vapes & e-cigarettes.* https://www.180smoke.ca/disposable-vapes-ecigarettes

Abdullah, A. H., Chowdhury, G., Adikari, D., Jahan, I., Andrawina, Y. O., Hossain, M. A., Schneider, P., & Iqbal, M. M. (2022). Macroplastics pollution in the Surma River in Bangladesh: A threat to fish diversity and freshwater ecosystems. *Water 2022, 14*(20), Article 3263. https://doi.org/10.3390/w14203263

Agriculture and Agri-Food Canada. (2025). *Canada: Outlook for principal field crops, 2025.* https://agriculture.canada.ca/sites/default/files/documents/2025-12/Canada%20Outlook%20for%20Principal%20Field%20Crops_202512.pdf

Alberta Government. (2015). *2015 Municipal affairs population list.* http://municipalaffairs.alberta.ca/documents/msb/2015_municipal_affairs_population_list.pdf

Alberta Government. (2023). *Percent single family houses by municipality.* https://open.alberta.ca/opendata/percent-single-family-houses-by-municipality

ALD Vapor. (2024). *Common materials and development process for e-cigarette plastic shells.* https://www.aldvapor.com/common-materials-and-development-process-for-e-cigarette-plastic-shells/

Amazon. (2026). *Foam trays.* https://www.amazon.ca/s?k=foam+trays&crid=3041E2IC4HM1J&sprefix=foam+tray%2Caps%2C179&ref=nb_sb_noss_2

Andrady, A. L. (2017). The plastic in microplastics: A review. *Marine Pollution Bulletin, 119*(1), 12–22.

Astner, A. F., Gillmore, A. B., Yu, Y., Flury, M., DeBruyn, J. M., Schaeffer, S. M., & Hayes, D. G. (2023). Formation, behavior, properties and impact of micro- and nanoplastics on agricultural soil ecosystems (a review). *NanoImpact, 31,* Article 100474. https://doi.org/10.1016/j.impact.2023.100474

Atugoda, T., Vithanage, M., Wijesekara, H., Bolan, N., Sarmah, A. K., Bank, M. S., You, S., & Ok, S. Y. (2021). Interactions between microplastics, pharmaceuticals and personal care products: Implications for vector transport. *Environment International 149* (2021): Article 106367. https://doi.org/10.1016/j.envint.2020.106367

Baker, J., Johanos, T. C., Ronco, H., Becker, B. L., Moriokam J., O'Brien, K., & Donohue, M. (2024). Four decades of Hawaiian monk seal entanglement data reveal the benefits of plastic debris removal. *Science, 385*(6716), 1491–1495. https://doi.org/10.1126/science.ado2834

Barnes, D. K. A. (2002). Biodiversity: Invasions by marine life on plastic debris. *Nature 416*(6883), 808–809.

Batista, Daniela, Pradhan, A., Pascoal, C., & Cássio, F. (2022). Evidence of micro and macroplastic toxicity along a stream detrital food-chain. *Journal of Hazardous Materials, 436,* Article 129064. https://doi.org/10.1016/j.jhazmat.2022.129064

Battisti, C., & S. Gippoliti. (2019). Not just trash! Anthropogenic marine litter as a "charismatic threat" driving citizen-based conservation management actions. *Animal Conservation 22*(4), 311–313. https://doi.org/10.1111%2Facv.12473

Beaumont, N. J., Aanesen, M., Austen, M. C., Börger, T., Clark, J. R., Cole, M., Hooper, T., Lindeque, P. L., Pascoe, C., & Wyles, K. J. (2019). Global ecological, social and economic impacts of marine plastic. *Marine Pollution Bulletin, 142,* 189–195. https://doi.org/10.1016/j.marpolbul.2019.03.022

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,* Article 144165.

Blettler, M. C., & Mitchell, C. (2021). Dangerous traps: Macroplastic encounters affecting freshwater and terrestrial wildlife. *Science of the Total Environment, 798,* Article 149317.

Borunda, A. (2019, September 6). How tampons and pads became so unsustainable. National Geographic, 73(1). https://doi.org/10.1016/j.yrtph.2015.07.028

Bottle Bill Resource Guide. (n.d.). *All Canada bottle bills.* Container Recycling Institute. https://www.bottlebill.org/legislation/canada/allprovstable.htm

Boyd, J., & Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics, 63*(2), 616–626. https://doi.org/10.1016/j.ecolecon.2007.01.002

Bucci, K., Tulio, M., & Rochman, C. M. (2020). What is known and unknown about the effects of plastic pollution: A meta-analysis and systematic review. *Ecological Applications 30*(2), Article e02044.

Carter, A. W., Sadd, B. M., Tuberville, T. D., Paitz, R. T., & Bowden, R. M. (2018). Short heatwaves during fluctuating incubation regimes produce females under temperature-dependent sex determination with implications for sex ratios in nature. *Scientific Reports, 8*(3), 1–18. https://doi.org/10.1038/s41598-017-17708-0

Circular Materials. (2025). *Toronto.* https://www.circularmaterials.ca/resident-communities/toronto/

Circulr. (n.d.). *The environmental impact of single-use plastic cups in Canada and why reusable cups are the future.* https://circulr.ca/2024/10/29/the-environmental-impact-of-single-use-plastic-cups-in-canada-and-why-reusable-cups-are-the-future/

City of Brandon. (2024). *Financial plan.* https://www.brandon.ca/media/o3pplydi/financial_plan_2024.pdf

City of Brandon. (2025). *Annual schedule of fees.* https://www.brandon.ca/media/4ofafzfx/2025_fee_schedule.pdf

City of Edmonton. (2019). *2019 City of Edmonton litter audit report.* https://www.edmonton.ca/sites/default/files/public-files/documents/PDF/COE-2019-Litter-Report.pdf

City of Edmonton. (2024). *Waste services 2025 rate filing*. https://pub-edmonton.escribemeetings.com/filestream.ashx?DocumentId=241679

City of Edmonton. (2025a). *Curbside collection.* https://www.edmonton.ca/programs_services/garbage_waste/curbside-cart-collection

City of Edmonton. (2025b). *Extended producer responsibility.* https://www.edmonton.ca/programs_services/garbage_waste/extended-producer-responsibility

City of Edmonton. (2025c). *Single-use item reduction.* https://www.edmonton.ca/programs_services/garbage_waste/single-use-items

City of Toronto. (2022). *2022 litter audit.* https://www.toronto.ca/wp-content/uploads/2023/11/8915-CityofTorontoLitterAudit2022FINALAODA.pdf

City of Toronto. (2024). *Solid waste reports & diversion rates.* https://www.toronto.ca/services-payments/recycling-organics-garbage/solid-waste-reports/#:~:text=2024%20Residential%20Diversion%20Rates,-The%202024%20diversion&text=The%202024%20diversion%20rate%20for%20multi%2Dresidential%20buildings%20was%2027.3,53.6%20per%20cent%20in%202023.%20;

City of Winnipeg. (2024). *Residential garbage, recycling and yard waste tonnage reports.* https://data.winnipeg.ca/Organizational-Support-Services/Residential-Garbage-Recycling-and-Yard-Waste-Tonna/fgza-8s5e/about_data

City of Yellowknife. (2018). *Strategic waste management plan.* https://www.yellowknife.ca/en/living-here/resources/Garbage/2018-Resources/DOCS-519171-v1-STRATEGIC_WASTE_MANAGEMENT_PLAN_-_FINAL_VERSION_-_UPDATED_MAY_7__2018_WITH_CORRECT_APPENDICES.pdf

Cleanfarms. (2021). *Agricultural plastic characterization and management on Canadian farms.* https://cleanfarms.ca/wp-content/uploads/2021/08/Project-Building-a-Canada-Wide-Zero-Plastic-Waste-Strategy-for-Agriculture.pdf

Coffee cups among many items you actually can't recycle, City says. (2016, June 21). CBC News. https://www.cbc.ca/news/canada/toronto/programs/metromorning/recycling-campaign-1.3645025

Coffin, S., Bouwmeester, H., Brander, S., Damdimopoulou, P., Gouin, T., Hermabessiere, L., Khan, E., Koelmans, A. A., Lemieux, C. L., Teerds, K., Wagner, M., Weisberg, S. B., & Wright, S. (2022). Development and application of a health-based framework for informing regulatory action in relation to exposure of microplastic particles in California drinking water. *Microplastics and Nanoplastics, 2*(1), 12. https://doi.org/10.1186/s43591-022-00030-6

Cosier, S. (2021). *A growing concern: Microplastic pollution on farm fields.* Natural Resources Defense Council. https://www.nrdc.org/stories/growing-concern-microplastic-pollution-farm-fields

Dal Pio Luogo, B., & Cascini, G. (2025). Understanding the flows of microplastic fibres in the textile lifecycle: A system perspective. *Sustainability, 17*(19), Article 8726. https://doi.org/10.3390/su17198726

Davis, J. (2019, April 10). *Styrofoam facts —Why you may want to bring your own cup.* SEJ Issue Backgrounder. https://www.sej.org/publications/backgrounders/styrofoam-facts-why-you-may-want-bring-your-own-cup

Deng, Y., Zeng, Z., Feng, W., Liu, J., & Yang, F. (2024). Characteristics and Migration Dynamics of Microplastics in Agricultural Soils. *Agriculture, 14*(1), 157. https://doi.org/10.3390/agriculture14010157

District of Squamish. (2024). *Zero waste.* District of Squamish. https://squamish.ca/sustainability-and-green-living/green-living/zerowaste/

Divert Nova Scotia. (2021). Nova Scotia roadside litter audits. https://divertns.ca/sites/default/files/researchreportsfiles/2022-03/2021%20Divert%20NS%20Litter%20Audit%20Report.pdf

Divert Nova Scotia. (2023a). *Municipal solid waste curbside collection tonnage.* Government of Nova Scotia. https://data.novascotia.ca/Environment-and-Energy/Municipal-Solid-Waste-Curbside-Collection-Tonnage/r7ci-8szi/about_data

Divert Nova Scotia. (2023b). *Municipal solid waste disposal totals.* Government of Nova Scotia. https://data.novascotia.ca/Environment-and-Energy/Municipal-Solid-Waste-Disposal-Totals/mp68-kdz7/about_data

Divert Nova Scotia. (2023c). *Nova Scotia's landfill waste audit 2023.* Government of Nova Scotia. https://divertns.ca/sites/default/files/researchreportsfiles/2024-04/2023%20NS%20Provincial%20Waste%20Audit.pdf

Dobaradaran, S., Schmidt, T. C., Lorenzo-Parodi, N., Kaziur-Cegla, W., Jochmann, M. A., Nabipour, I., Lutze, H. V., & Telgheder, U. (2020). Polycyclic aromatic hydrocarbons (PAHs) leachates from cigarette butts into water. *Environmental Pollution, 259,* Article 113916.

Dobaradaran, S., Telgheder, U., De-la-Torre, G. E., Rockel, S. P., Mutke, X. A. M., & Schmidt, T. C. (2024). Elucidating nicotine transfer into water environments via cigarette butt remaining parts. *Environmental Pollution, 341,* Article 122943. https://doi.org/10.1016/j.envpol.2023.122943

Don't flush your flushable wipes, city and students remind Londoners. (2023, March 21). CBC News. https://www.cbc.ca/news/canada/london/flushable-wipes-london-reminder-1.6784710

Dos Santos, N. P., Maciel, M. G. R., Guimarães, P. S., Trinidade, C. R. T., & Schenk, F. (2024). Negative effects of cigarette butt leachate on freshwater phytoplankton communities. *Ecotoxicology, 33*(8), 884–892.

Egger, M., Quiros, L., Leone, G., Ferrarri, F., Boerger, C. M., & Tishler, M. (2021). Relative abundance of floating plastic debris and neuston in the Eastern North Pacific Ocean. *Frontiers in Marine Science, 8,* Article 626026. https://doi.org/10.3389/fmars.2021.626026

Environment and Climate Change Canada. (2019). *Economic study of the Canadian plastic industry, markets and waste.* Government of Canada. https://publications.gc.ca/collections/collection_2019/eccc/En4-366-1-2019-eng.pdf

Environment and Climate Change Canada. (2020). *Science assessment of plastic pollution.* Government of Canada. https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/science-assessment-plastic-pollution.html#toc29

European Commission. (2021). *Study to support the development of implementing acts and guidance under the Directive on the reduction of the impact of certain plastic products on the environment.* https://doi.org/10.2779/270147

Ferreira, V. (2024). Macroplastic litter colonization by stream macroinvertebrates relative to that of plant litter: A meta-analysis. *Environmental Pollution 342,* Article 123108. https://doi.org/10.1016/j.envpol.2023.123108

Gall, S. C., & Thompson, R. C. (2015). The impact of debris on marine life. *Marine Pollution Bulletin, 92*(1–2), 170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041

Gallitelli, L., & Scalici, M. (2023). Can macroplastics affect riparian vegetation blooming and pollination? First observations from a temperate South-European river. *Ecological Indicators, 154,* Article 110531. https://doi.org/10.1016/j.ecolind.2023.110531

Gallitelli, L., Cesarini, G., Sodo, A., & Scalici, M. (2023). Life on bottles: Colonisation of macroplastics by freshwater biota. *Science of the Total Environment, 873,* Article 162349. https://doi.org/10.1016/j.scitotenv.2023.162349

Gao, G. H. Y., Helm, P., Baker, S., & Rochman, C. M. (2023). Bromine content differentiates between construction and packaging foams as sources of plastic and microplastic pollution. *ACS ES&T Water, 3*(3), 876–884.

GFL. (2026). *About us.* https://gflenv.com/about-us/

Ghasemi, A., Mofrad, M., M., G., Parseh, I., Hassani, G., Mohammadi, H., Hayati, R., & Alinejad, N. (2022). Cigarette butts as a super challenge in solid waste management: A review of current knowledge. *Environmental Science and Pollution Research, 29*(34), 51269–51280.

Gies, E. A., LeNoble, J. L., Noël, M., Etemadifar, A., Bishay, F., Hall, E. R., & Ross, P. S. (2018). Retention of microplastics in a major secondary wastewater treatment plant in Vancouver, Canada. *Marine Pollution Bulletin, 133,* 553–561. https://doi.org/10.1016/j.marpolbul.2018.06.006

Godoy, V., Prata, J. C., Blázquez, G., Calero, M., Quesada, L., & Martín-Lara, M. A. (2019). The potential of microplastics as carriers of metals. *Environmental Pollution, 255,* Article 113363. https://doi.org/10.1016/j.envpol.2019.113363

Government of Canada. (2024). *Municipal solid waste management in Canada.* https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/municipal-solid/environment.html

Government of Canada. (2025). *Overview of Canada's agriculture and agri-food sector.* https://agriculture.canada.ca/en/sector/overview

Government of Northwest Territories. (2024). *Waste reduction and recovery program.* https://www.gov.nt.ca/ecc/sites/ecc/files/resources/waste_annualreport_2022-23_web.pdf

Green, D. S., Tongue, A. D. W., & Boots, B. (2022). The ecological impacts of discarded cigarette butts. *Trends in Ecology & Evolution 37*(2), 183–192.

Green, D. S., Kregting, L., Boots, B., & Rocha-Santos, T. (2023). Time to kick the butt of the most common litter item in the world: Ban cigarette filters. *Science of the Total Environment, 865,* 161256. https://doi.org/10.1016/j.scitotenv.2022.161256

Green, D. S., Boots, B., Blockley, D. J., (2015). Impacts of discarded plastic bags on marine assemblages and ecosystem functioning. *Environmental Science & Technology, 49*(9), 5380–5389. https://doi.org/10.1021/es506013r

Green, D. S., Kregting, L., & Boots. (2020). Smoked cigarette butt leachate impacts survival and behaviour of freshwater invertebrates. *Environmental Pollution 266*(3), Article 115286.

Gregory, M. R. (2009). Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of the Royal Society B: Biological Sciences 364*(1526), 2013-2025.

Gündoğdu, S., Yeşilyurt, I. M., & Erbaş, C. (2019). Potential interaction between plastic litter and green turtle Chelonia mydas during nesting in an extremely polluted beach. *Marine Pollution Bulletin, 140,* 138–145

Hahladakis, J. N., Velis, C. A., Weber, R., Iacovidou, E., & Purnell, P. (2018). An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. *Journal of Hazardous Materials, 344,* 179–199. https://doi.org/10.1016/j.jhazmat.2017.10.014

Haney, J., Zhu, X., Long, M., Schwenk, B. A., Hoellein, T. J., Wollheim, W. M., Lammers, R. B., Zuidema, S., & Rochman, C. M. (2025). The influence of flow on the amount, retention and loss of plastic pollution in an urban river. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences, 383*(2307), Article 20230023. https://doi.org/10.1098/rsta.2023.0023

Haney, J., & Rochman, C. M. (2025). Plastic pollution has the potential to alter ecological and evolutionary processes in aquatic ecosystems. *Nature Ecology & Evolution, 9,* 1–7.

Hataley, E., McIlwraith, H. K., Roy, D., & Rochman, C. M. (2023). Towards a management strategy for microplastic pollution in the Laurentian Great Lakes—ecological risk assessment and management (part 2). *Canadian Journal of Fisheries and Aquatic Sciences, 80*(10), 1669–1678. https://doi.org/10.1139/cjfas-2023-0023

Health Canada. (2022). *Canadian tobacco and nicotine survey (CTNS): Summary of results for 2022.* Government of Canada. https://www.canada.ca/en/health-canada/services/canadian-tobacco-nicotine-survey/2022-summary.html

Health Canada. (2024). *Tobacco sales trends in Canada 2001-2023.* Government of Canada. https://www.smoke-free.ca/pdf_1/2025/Canada%20Tobacco%20Sales_2001-2023.pdf

Hermabessiere, L., Dehaut, A., Paul-Pont, I., Lacroix, C., Jezequel, R., Soudant, P., & Duflos, G. (2017). Occurrence and effects of plastic additives on marine environments and organisms: A review. *Chemosphere, 182,* 781–793. https://doi.org/10.1016/j.chemosphere.2017.05.096

Hoffmann, D., & Hoffmann, I. (1998). Chemistry and toxicology. In D. Shopland (Ed.), *Cigars: Health effects and trends* (pp. 55–104). Diane Publishing.

International Water Services Flushability Group. (2026). *IWSFG Flushability specifications.* https://www.iwsfg.org/iwsfg-flushability-specification/

Jagiello, Z., Dylewski, L, Tobolka, M., & Aguirre, J. I. (2019). Life in a polluted world: A global review of anthropogenic materials in bird nests. *Environmental Pollution, 251,* 717–722.

Jang, Y. C., Hong, S., Lee, J., Lee, M. J., & Shim, W. J. (2014). Estimation of lost tourism revenue in Geoje Island from the 2011 marine debris pollution event in South Korea. *Marine Pollution Bulletin 81*(1), 49-54.

Jin, Y., Lu, L., Tu, W., Luo, T. & Fu, Z. (2019). Impacts of polystyrene microplastic on the gut barrier, microbiota and metabolism of mice. *Science of The Total Environment, 649,* 308-317. https://doi.org/10.1016/j.scitotenv.2018.08.353

Julienne, F., Delorme, N., & Lagarde, F. (2019). From macroplastics to microplastics: Role of water in the fragmentation of polyethylene. *Chemosphere, 236,* Article 124409. https://doi.org/10.1016/j.chemosphere.2019.124409

Kahane-Rapport, S. R., Czapanskiy, M. F., Fahlbusch, J. A., Friedlaender, A. S., Calambokidis, J., Hazen, E. L., Goldbogen, J. A., & Savoca, M. S. (2022). Field measurements reveal exposure risk to microplastic ingestion by filter-feeding megafauna. *Nature Communications, 13*(1), Article 6327. https://doi.org/10.1038/s41467-022-33334-5

Katlam, G., Prasad, S., Pande, A., & Ramchiary, N. (2022). Plastic ingestion in Asian elephants in the forested landscapes of Uttarakhand, India. *Journal for Nature Conservation, 68,* Article 126196. https://doi.org/10.1016/j.jnc.2022.126196

Kaza, S., Yao, L. C., Bhada-Tata, P., & Van Woerden, F. (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050.* World Bank Group. https://doi.org/10.1596/978-1-4648-1329-0

Kennedy, K. T. M., & El-Sabaawi, R. W. (2018). Decay patterns of invasive plants and plastic trash in urban streams. *Urban Ecosystems, 21*(5), 817–830. https://doi.org/10.1007/s11252-018-0771-9?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

Kim, J. W., Jeon, J., Seo, H., Cho, D., & Kim, S. W. (2020). Functional expression of polyethylene terephthalate-degrading enzyme (PETase) in green microalgae. *Microbial Cell Factories, 19(*1), 1–9. https://doi.org/10.1186/s12934-020-01355-8

Klimasz, M., & Grobelak, A. (2025). Effects of microplastics on selected earthworm species. *Toxics, 13*(3), Article 201. https://doi.org/10.3390/toxics13030201

Koelmans, A., Redondo-Hasselerharm, P., Hazimah, N., Ruijter, V., Mintenig, S., & Kooi, M. (2022). Risk assessment of microplastic particles. *Nature Reviews Materials, 7*(2), 138–152

Kühn, S., & van Franeker, J. A. (2020). Quantitative overview of marine debris ingested by marine megafauna. *Marine Pollution Bulletin, 151,* Article 110858. https://doi.org/10.1016/j.marpolbul.2019.110858

Kumar, R., Bhatia, M., Singh, R., Singh, R., & Singh, S. (2021). Impacts of plastic pollution on ecosystem services, sustainable development goals, and need to focus on circular economy and policy interventions. *Sustainability, 13*(17), Article 9963. https://doi.org/10.3390/su13179963

Lamb, J. B., Willis, B. L., Fiorenza, E. A., Couch, C. S., Howard, R., Rader, D. N., True, J. D., Kelly, L. A., Ahmad, A., & Jompa, J. (2018). Plastic waste associated with disease on coral reefs. *Science, 359*(6374), 460–462. https://doi.org/10.1126/science.aar3320

Lauer, N., Vegh, T., Nowlin, M., Virdin, J., & Somarelli, J. (2025). *The social cost of plastic to the United States* (NI R 25-09). Nicholas Institute for Energy, Environment & Sustainability, Duke University. https://nicholasinstitute.duke.edu/publications/social-cost-plastic-united-states

Leggett, C. G., Adams, C., Bockstael, N., & McConnell, K. (2014). *Assessing the economic benefits of reductions in marine debris: A pilot study of beach recreation in Orange County, California.* Industrial Economics, Incorporated.

Liro, M., Zielonka, A., & van Emmerik, T. H. M. (2023). Macroplastic fragmentation in rivers. *Environment International, 180,* Article 108186. https://doi.org/10.1016/j.envint.2023.108186

Mallory, M. L., Baak, J., Gjerdrum, C., Mallory, O. E., Manley, B., Swan, C., & Provencher, J. F. (2021). Anthropogenic litter in marine waters and coastlines of Arctic Canada and West Greenland. *Science of the Total Environment, 783,* Article 146971. https://doi.org/10.1016/j.scitotenv.2021.146971

Macrotrends. (2025). *Edmonton, Canada metro area population (1950-2025)*. https://www.macrotrends.net/global-metrics/cities/20373/edmonton/population#:~:text=The%20metro%20area%20population%20of%20Edmonton%20in%202023%20was%201%2C544%2C000,a%201.88%25%20increase%20from%202021

Maquart, P. O., Froehlich, Y., & Boyer, S. (2022). Plastic pollution and infectious diseases. The Lancet. *Planetary Health, 6*(10), e842–e845. https://doi.org/10.1016/S2542-5196(22)00198-X

Mehinto, A. C., Coffin, S., Koelmans, A. A., Brander, S. M., Wagner, M., Thornton Hampton, L. M., Burton, A. G., Miller, E., Gouin, T., Weisberg, S. B., & Rochman, C. M. (2022). Risk-based management framework for microplastics in aquatic ecosystems. *Microplastics and Nanoplastics, 2*(1), 17.

Menezes, R., da Cunha-Neto, M. A., de Mesquita, G. C., & da Silva, G. B. (2019). Ingestion of macroplastic debris by the common dolphinfish (Coryphaena hippurus) in the Western Equatorial Atlantic. *Marine Pollution Bulletin, 141,* 161–163. https://doi.org/10.1016/j.marpolbul.2019.02.026

Milne, M. H., Helm, P. A., Munno, K., Bhavsar, S. P., & Rochman, C. M. (2024). Microplastics and anthropogenic particles in recreationally caught freshwater fish from an urbanized region of the North American Great Lakes. *Environmental Health Perspectives, 132*(7), Article 77004. https://pmc.ncbi.nlm.nih.gov/articles/PMC11253813/pdf/ehp13540.pdf

Mission Zero. (2025). *FAQs—Disposable water bottles.* https://missionzero.sheridancollege.ca/faqs/disposable-water-bottles/

Multi-Material Stewardship Manitoba. (2025a). 2024 MMSM Multi-Family Waste Composition Study, May 22, 2025. Privately obtained.

Multi-Material Stewardship Manitoba(2025b). 2024 MMSM Brandon Multi-Family Waste Composition Study, May 22, 2025. Privately obtained.

Mohammadi, H., Morovati, M., Zardosht, Z., & Hassani, G. (2024). Assessment of uncontrolled PAHs leakage from littered cigarette butts into the urban environment. *International Journal of Environmental Analytical Chemistry, 104*(20), 9234–9245. https://doi.org/10.1080/03067319.2023.2228203

Murphy, E. L., Baechler, B. R., Roman, L., Leonard, G. H., Mallos, N. J., Santos, R. G., & Rochman, C. M. (2025). A quantitative risk assessment framework for mortality due to macroplastic ingestion in seabirds, marine mammals, and sea turtles. *PNAS 122*(48), Article e2415492122. https://doi.org/10.1073/pnas.2415492122

Murphy, E. L., Gerber, L. R., Rochman, C. M., & Polidoro, B. (2024). A macroplastic vulnerability index for marine mammals, seabirds, and sea turtles in Hawai 'i. *Science of the Total Environment, 908,* Article 168247. https://doi.org/10.1016/j.scitotenv.2023.168247

National Environment Agency. (2015, October). *Packaging benchmarking database (water)*. https://www.nea.gov.sg/docs/default-source/our-services/packaging-benchmarks-(water).pdf

Nelms, S. E., Duncan, E. M., Broderick, A. C., Galloway, T. S., Godfrey, M. H., Hamann, M., Lindeque, P. K., & Godley, B. J. (2016). Plastic and marine turtles: a review and call for research. *ICES Journal of Marine Science, 73*(2), 165–181. https://doi.org/10.1093/icesjms/fsv165

Novillo, O., Raga, J. A., & Tomás, J. (2020). Evaluating the presence of microplastics in striped dolphins (Stenella coeruleoalba) stranded in the Western Mediterranean Sea. *Marine Pollution Bulletin, 160,* Article 111557. https://doi.org/10.1016/j.marpolbul.2020.111557

Novotny, T. E., Lum, K., Smith, E., Wang, V., & Barnes, R. (2009). Cigarette butts and the case for an environmental policy on hazardous cigarette waste. *International Journal of Environmental Research and Public Health, 6*(5), 1691–1705. https://doi.org/10.3390/ijerph6051691

Ocean Conservancy. (n.d.). *Cleanup reports.* https://oceanconservancy.org/work/plastics/cleanups-icc/annual-data-release/

Ocean Conservancy. (2024). *Trash information and data for education and solutions (TIDES) dataset.* www.coastalcleanupdata.org

Organization for Economic Co-operation and development. (2022). *Annex A. Modelling approaches used to compose the OECD global plastics outlook database*. https://www.oecd.org/en/publications/global-plastics-outlook_de747aef-en/full-report.html#annex-d1e20807

Perez Venegas, D. J., Valenzuela Sánchez, A., Montalva, F., Pavés, H., Seguel, M., Wilcox, C., & Galbán Malagón, C. (2021). Towards understanding the effects of oceanic plastic pollution on population growth for a South American fur seal *(Arctocephalus australis australis)* colony in Chile. *Environmental Pollution, 279,* 116881. https://doi.org/10.1016/j.envpol.2021.116881

Perrone, M. (2023). Communities can't recycle or trash disposable e-cigarettes. So what happens to them? *Winnipeg Free Press.* https://www.winnipegfreepress.com/arts-and-life/life/2023/10/19/communities-cant-recycle-or-trash-disposable-e-cigarettes-so-what-happens-to-them

Physicians for a Smoke-Free Canada. (2020). *Single use plastics and tobacco waste* (Updated 2022). https://smoke-free.ca/SUAP/2020/Single-Use-Plastics-and-Tobacco-Waste.pdf

Poppi, L., Zaccaroni, A., Pasotto, D., Dotto, G., Marcer, F., Scaravelli, D., & Mazzariol, S. (2012). Post mortem investigations on a leatherback turtle Dermochelys coriacea stranded along the Northern Adriatic coastline. *Diseases of Aquatic Organisms, 100*(1), 71–76. https://doi.org/10.3354/dao02479

Prikaziuk, E., Migliavacca, M., Su, Z., & van der Tol, C. (2023). Simulation of ecosystem fluxes with the SCOPE model: Sensitivity to parametrization and evaluation with flux tower observations. *Remote Sensing of Environment, 284,* Article 113324. https://doi.org/10.1016/j.rse.2022.113324

Provencher, J. F., Bond, A. L., & Mallory, M. L. (2015). Marine birds and plastic debris in Canada: A national synthesis and a way forward. *Environmental Reviews, 23*(1), 1–13. https://doi.org/10.1139/er-2014-0039

Puckowski, A., Cwięk, W., Mioduszewska, K., Stepnowski, P., & Białk Bielińska, A. (2021). Sorption of pharmaceuticals on the surface of microplastics. *Chemosphere, 263,* Article 127976. https://doi.org/10.1016/j.chemosphere.2020.127976

Rabson, M. (2024, April 25). *Billions of bottles: Statistics paint grim picture of Canada's plastic problem.* Canadian Press. https://www.terracestandard.com/national-news/billions-of-bottles-statistics-paint-grim-picture-of-canadas-plastic-problem-7349990

Raes, L., Mittempergher, D., Jain, A. (2023). *The economic impact of plastic pollution, and the benefits of reducing mismanaged waste.* International Union for Conservation of Nature and Natural Resources. https://iucn.org/resources/grey-literature/economic-impact-plastic-pollution-and-benefits-reducing-mismanaged-waste

Raman-Wilms, M. (2020, November 8). *Why some environmentalists are pushing for an end to plastic tampon applicators.* CBC News. https://www.cbc.ca/news/science/why-some-environmentalists-are-pushing-for-an-end-to-plastic-tampon-applicators-1.5788186

Ratelle, M., Haig, L., Laird, B. D., & Skinner, K. (2021). Game bird consumption in Dene communities of the Northwest Territories, Canada. *Public Health Nutrition, 24*(6), 1229–1239. https://doi.org/10.1017/S1368980021000021

Rech, S., Borrell, Y., & García Vázquez, E. (2016). Marine litter as a vector for non native species: What we need to know. *Marine Pollution Bulletin, 113*(1–2), 40–43. https://doi.org/10.1016/j.marpolbul.2016.08.032

Recycle BC. (2024). *Annual report*. https://recyclebc.ca/about/annual-reports/

Ripley, S. (2018). *Options for waste diversion targets and tactics.* Cubed Environmental. Town of Banff. https://banff.ca/DocumentCenter/View/8523/Waste-Diversion-Targets-and-Tactics-Report

Salam, M., Zheng, H., Liu, Y., Zaib, A., Rehman, S. A. U., Riaz, N., Eliw, M., Hayat, F., Li, H., & Wang, F. (2023). Effects of micro(nano)plastics on soil nutrient cycling: State of the knowledge. *Journal of Environmental Management, 344,* Article 118437. https://doi.org/10.1016/j.jenvman.2023.118437

Salama, K., & Geyer, M. (2023). Plastic mulch films in agriculture: Their use, environmental problems, recycling and alternatives. *Environments, 10*(10), Article 179. https://doi.org/10.3390/environments10100179

Savchuk, K. (2025, January 29). *Microplastics and our health: What the science says.* Stanford Medicine. https://med.stanford.edu/news/insights/2025/01/microplastics-in-body-polluted-tiny-plastic-fragments.html

Schwarcz, J. (2022, October 14). *Can the plastic caps on water or soda bottles be recycled?* You Asked. https://www.mcgill.ca/oss/article/you-asked/can-plastic-caps-water-or-soda-bottles-be-recycled

Senko, J. F., Nelms, S. E., Reavis, J. L., Witherington, B., Godley, B. J., & Wallace, B. P. (2020). Understanding individual and population-level effects of plastic pollution on marine megafauna. *Endangered Species Research, 43,* 234–252. https://doi.org/10.3354/esr01064

Shahzad, M. K., Khan, M., Soomro, F., Zaman, Q., Sultan, K., & Thebo, K. (2022). Mass characterisation of elemental toxicants in popular cigarettes sale in Pakistan using ICP-OES. *International Journal of Environmental Analytical Chemistry 104*(1), 1–14. https://doi.org/10.1080/03067319.2022.2120394?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

Solid Waste Management Services. (2025). *2025 budget notes solid waste management services.* City of Toronto. https://www.toronto.ca/legdocs/mmis/2025/bu/bgrd/backgroundfile-252508.pdf

Sperling Hansen Associates. (2025). *Squamish landfill annual operations and monitoring report 2024.* District of Squamish.

Sridharan, S., Kumar, M., Bolan, N. S., Singh, L., Kumar, S., Kumar, R., & You, S. (2021). Are microplastics destabilizing the global network of terrestrial and aquatic ecosystem services? *Environmental Research, 198,* Article 111243. https://doi.org/10.1016/j.envres.2021.111243

Statistics Canada. (2019). *Classification of sources of waste.* Government of Canada. https://www23.statcan.gc.ca/imdb/p3VD.pl?Function=getVD&TVD=1231840&CVD=1231840&CLV=0&MLV=1&D=1

Statistics Canada. (2021a). *2021 census of population: Halifax.* Government of Canada. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&SearchText=halifax&GENDERlist=1,2,3&STATISTIClist=1&DGUIDlist=2021S0503205&HEADERlist=0

Statistics Canada. (2021b). *2021 census of population: Winnipeg.* Government of Canada. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&SearchText=winnipeg&GENDERlist=1&STATISTIClist=1&DGUIDlist=2021A00054611040&HEADERlist=0

Statistics Canada. (2021c). *2021 census of population: Squamish.* Government of Canada. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&SearchText=Squamish&DGUIDlist=2021A00055931006&GENDERlist=1,2,3&STATISTIClist=1&HEADERlist=0

Statistics Canada. (2021d). *2021 census of population: Yellowknife.* Government of Canada. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&GENDERlist=1&STATISTIClist=1&HEADERlist=0&DGUIDlist=2021A00056106023&SearchText=yellowknife

Statistics Canada. (2021e). *2021 census of population: Brandon.* Government of Canada. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&SearchText=Brandon&DGUIDlist=2021S0504610&GENDERlist=1,2,3&STATISTIClist=1&HEADERlist=0

Statistics Canada. (2021f). *2021 census of population: Toronto.* Government of Canada. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&GENDERlist=1&STATISTIClist=1&HEADERlist=0&DGUIDlist=2021A00053520005&SearchText=toronto

Statistics Canada. (2021g). *2021 census of population: Edmonton.* Government of Canada. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&SearchText=edmonton&GENDERlist=1&STATISTIClist=1&DGUIDlist=2021A00054811061&HEADERlist=0

Statistics Canada. (2021h). *2021 census of population: Banff.* Government of Canada. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&SearchText=Banff&DGUIDlist=2021S05100040&GENDERlist=1,2,3&STATISTIClist=1&HEADERlist=0

Statistics Canada. (2023, June 9). *The message in a bottle: Plastic packaging waste.* Statistics Canada. https://www.statcan.gc.ca/o1/en/plus/3797-message-bottle-plastic-packaging-waste

Statistics Canada. (2024). *Disposal of waste, by source.* Government of Canada. https://doi.org/10.25318/3810003201-eng

Statistics Canada. (2026). *Table 32-10-0359-01 Estimated areas, yield, production, average farm price and total farm value of principal field crops, in metric and imperial units.* https://doi.org/10.25318/3210035901-eng

Sy D. K. (2024). Tobacco industry accountability for marine pollution: country and global estimates. *Tobacco Control, 33*(e2), e1–e4. https://doi.org/10.1136/tc-2022-057795

Tetra Tech. (2024). *Eastview landfill 2024 annual operations report.* City of Brandon. https://www.brandon.ca/media/uvyfgca1/eastview-landfill-2024-operations-report.pdf

Teuten, E. L., Saquing, J. M., Knappe, D. R., Barlaz, M., Jonsson, S., Björn, A., Rowland, S. J., Thompson, R. C., Galloway, T. S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P. H., Tana, T. S., Prudente, M., Boonyatumanond, R., Zakaria, M. P., Akkhavong, K., … Takada, H. (2009). Transport and release of chemicals from plastics to the environment and to wildlife. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1526), 2027–2045. https://doi.org/10.1098/rstb.2008.0284

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), Article 2045. https://doi.org/10.1038/s41598-021-81499-8

Thornton Hampton, L. M., Bouwmeester, H., Brander, S. M., Coffin, S., Cole, M., Hermabessiere, L., Mehinto, A. C., Miller, E., Rochman, C. M., & Weisberg, S. B. (2022). Research recommendations to better understand the potential health impacts of microplastics to humans and aquatic ecosystems. *Microplastics & Nanoplastics, 2,* 18. https://doi.org/10.1186/s43591-022-00038-y

Trewin, B. J., Kay, B. H., Carver, S., & Lindsay, M. D. (2013). Increased container-breeding mosquito risk owing to drought-induced changes in water harvesting and storage in Brisbane, Australia. *International Health, 5*(4), 251–258. https://pubmed.ncbi.nlm.nih.gov/24225151/

Tudor, D. T., & Williams, A. T. (2003). Public perception and opinion of visible beach aesthetic pollution: The utilisation of photography. *Journal of Coastal Research, 19*(4) 1104–1115.

U of T Trash Team. (n.d.). *Kicking plastic's butt: Cigarette butt fact sheet.* https://uofttrashteam.ca/wp-content/uploads/2022/06/Kicking-Plastics-Butt-Cigarette-Butt-Fact-Sheet.pdf

U.S. Department of Health and Human Services. (2004). *The health consequences of smoking: A report of the Surgeon General.* https://www.ncbi.nlm.nih.gov/books/NBK44695/

United Nations Environment Programme. (2008). *NOWPAP regional action plan on marine litter.*

United Nations, European Commission, Food and Agriculture Organization of the United Nations, Organisation for Economic Co-operation and Development, United Nations Environment Programme, & World Bank. (2024). *System of environmental-economic accounting ecosystem accounting.* https://seea.un.org/sites/seea.un.org/files/documents/EA/seea_ea_f124_web_12dec24.pdf

University of Waterloo. (2020). *E-cigarette use in Canada.* Tobacco Use in Canada. https://uwaterloo.ca/tobacco-use-canada/e-cigarette-use-canada

Vox, G., Loisi, R. V., Blanco, I., Mugnozza, G. S., & Schettini, E. (2016). Mapping of agriculture plastic waste. *Agriculture and Agricultural Science Procedia, 8,* 583–591. https://doi.org/10.1016/j.aaspro.2016.02.080

Walker, H., & Aherne, J. (2024). Microplastic fate in a chronosequence of biosolid-amended agricultural soil in Southern Ontario, Canada. *European Journal of Soil Science, 75*(5). https://doi.org/10.1111/ejss.13592

Water Canada. (2021, August 6). *Single-use plastic bottle waste the focus of new multi-media exhibit.* Water Canada. https://www.watercanada.net/single-use-plastic-bottle-waste-the-focus-of-new-multi-media-exhibit/

Why disposable vapes are becoming an environmental liability. (2023, May 5). CBC. https://www.cbc.ca/news/science/what-on-earth-disposable-vapes-1.6832312

Wilcox, C., van Sebille, E., & Hardesty, B. D. (2018). A quantitative analysis linking sea turtle mortality and plastic debris ingestion. *Scientific Reports, 8*(1), 12536. https://www.nature.com/articles/s41598-018-30038-z

World Bank. (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050.* https://openknowledge.worldbank.org/entities/publication/d3f9d45e-115f-559b-b14f-28552410e90a

World Wide Fund for Nature (Dalberg Advisors). (2021). *Plastics: The costs to society, the environment, and the economy.* https://wwflac.awsassets.panda.org/downloads/wwf_pctsee_report_english.pdf

WWF Australia. (2021, July 1). *The lifecycle of plastics.* WWF Australia. https://wwf.org.au/blogs/the-lifecycle-of-plastics/

Yan, F., Hermansen, C., Zhou, G., Knadel, M., & Norgaard, T. (2024). Meta-analysis shows that microplastics affect ecosystem services in terrestrial environments. *Journal of Hazardous Materials, 480,* Article 136379. https://doi.org/10.1016/j.jhazmat.2024.136379

Yang, Y., Liu, W., Zhang, Z., Grossart, H.-P., & Gadd, G. M. (2020). Microplastics provide new microbial niches in aquatic environments. *Applied Microbiology and Biotechnology, 104,* 6501–6511. https://doi.org/10.1007/s00253-020-10704-x

Zettler, E. R., Mincer, T. J., & Amaral Zettler, L. A. (2013). Life in the “plastisphere”: Microbial communities on plastic marine debris. *Environmental Science & Technology, 47*(13), 7137–7146. https://doi.org/10.1021/es401288x

Zhu, R., Zhang, Z., Zhang, N., Zhong, H., Zhou, F., Zhang, X., Liu, C., Huang, Y., Yuan, Y., Wang, Y., Li, C., Shi, H., Rillig, M. C., Dang, F., Ren, H., Zhang, Y., & Xing, B. (2025a). A global estimate of multiecosystem photosynthesis losses under microplastic pollution. *Proceedings of the National Academy of Sciences - PNAS, 122*(11), Article e2423957122. https://doi.org/10.1073/pnas.2423957122

Zhu, R., Zhang, Z., Zhang, N., Zhong, H., Zhou, F., Zhang, X., Liu, C., Huang, Y., Yuan, Y., Wang, Y., Li, C., Shi, H., Rillig, M. C., Dang, F., Ren, H., Zhang, Y., & Xing, B. (2025b). *Supporting information for a global estimate of multi-ecosystem photosynthesis losses under microplastic pollution.* https://www.pnas.org/doi/10.1073/pnas.2423957122#supplementary-materials

Appendix A. Additional Information on Single-Use Plastics

Plastic Beverage Bottles

Product Description

Plastic beverage bottles include any single-use water, juice, or pop bottle that is made of plastic (not glass or aluminum for the purposes of this research) and is closed using a cap. These bottles are readily available at nearly all grocery stores and convenience locations across Canada and are widely and commonly used by Canadians.

Composition, Plastic Content, Type of Plastic

Plastic beverage bottles are most commonly made from PET, or number 1 plastic. These bottles are made entirely from plastic, but because they are made in multiple different sizes, the grams of plastic in a bottle vary. The size that would be most commonly taken in a to-go setting would be a 500 ml bottle, which contains 12–27 g of PET, depending on the bottle design (NEA, 2015). A 2 L bottle weighs approximately 50–60 g, and a 1 L bottle weighs approximately 25–37g.

Volumes of Waste

Plastic bottles are one of the highest volume plastic waste products in Canada (Statistics Canada, 2023), and the volume of plastic bottles being disposed of in Canada is rising every year (Schwarcz, 2022). According to the latest Statistics Canada report, Canadians used 15 billion plastic bottles over an 8-year period, or just under 2 billion per year (Rabson, 2024). In 2019, the weight of plastic waste from just bottles was 471,393 tonnes (Statistics Canada, 2023). In the 2019 plastics survey, bottles were the only type of single-use plastic in which the amount of waste rose in each subsequent year (Statistics Canada, 2023).

What Happens to the Waste?

Plastic bottles made of PET can be recycled, but the proportion of people who remember to recycle their water bottles varies by location. In total, for the country, roughly 70% of plastic bottles are recycled (Mission Zero, 2025). When these bottles are disposed of correctly, they can be sold for a profit by recycling plants to manufacturers and turned into something else.

Years It Persists in the Environment

Plastic bottles are estimated to persist in the environment for at least 450 years, but this has never been tested since plastic has not existed that long (Water Canada, 2021).

Bottle Caps

Product Description

Bottle caps are the caps on disposable, plastic beverage bottles. They are commonly found on single-use water bottles, pop bottles, and juice bottles.

Composition, Plastic Content, Type of Plastic

Plastic bottle caps are made entirely of plastic, typically either HDPE (5) or PP (2) (Schwarcz, 2022). These are both forms of rigid plastic with high melting points (Schwarcz, 2022). A typical bottle cap will contain 2–3 g of plastic (Schwarcz, 2022).

Volumes of Waste

Since single-use beverage bottles and caps are only ever sold together, the number of caps being generated can be estimated using the amount of single-use bottles being disposed of. Plastic bottles and caps are one of the highest volume plastic waste products in Canada (Statistics Canada, 2023). The volume of plastic bottles being disposed of in Canada is rising every year (Schwarcz, 2022). According to the latest Statistics Canada report, Canadians used 15 billion plastic bottles over an 8-year period, or just under 2 billion per year (Rabson, 2024). If we assume each bottle cap weighed 2.5 g, this would be 4.7 million g (5 tons) of plastic per year just from the bottle caps.

What Happens to the Waste?

Ideally, plastic bottle caps should be recycled, a process which typically involves melting the plastic down (Schwarcz, 2022). However, not all Canadian municipalities have the infrastructure for recycling this plastic, and even where the infrastructure does exist, consumers don't always use proper waste disposal methods. Because of this, some Canadian cities have all plastic bottle caps either heading to landfill or being littered. Meanwhile others, like Winnipeg, have relatively high recycling rates of bottle caps.

Years It Persists in the Environment

Plastic bottle caps are estimated to persist in the environment for at least 450 years, but this has naturally never been tested since plastic has not existed that long (Water Canada, 2021).

Takeaway Cups (Hot)

Product Description

Takeaway cups for hot beverages do have some variation, but the most common type of plastic-containing hot cup is a paper cup with a PE lining. Most businesses that use these cups will stock them in different sizes so customers can choose the size of their beverage. The exact size of a "small," "medium," or "large" coffee varies by brand. For example, a small Tim Hortons coffee is 10 oz, but at Starbucks, the small size (called "tall") is 12 oz. This variability makes it more difficult to make consistent estimates of volumes of plastic waste from these cups.

Composition, Plastic Content, Type of Plastic

The plastic in most hot cups is PE (polyethylene), which is a thermoplastic. Takeaway hot cups are mostly constructed from paper, with the PE component only making up the lining, or about 5% of the total cup weight. Because of the large variation in cup sizes available, we will use a medium Tim Hortons cup as a standard example. A medium Tim Hortons hot cup is 14 oz and weighs about 30 g. This means it contains 1.5 g of plastic.

Volumes of Waste

The volume of waste from hot cups is difficult to estimate because they don't go to waste sorting facilities if properly disposed of. But in 2010, it was estimated that Canadians used 1.5 billion disposable coffee cups just that year (CBC News, 2016).

What Happens to the Waste?

Takeaway hot cups are not recyclable in most of Canada, so they must go to landfills and are also commonly littered. This is slowly changing in some larger cities, where they are being recycled.

Years It Persists in the Environment

A single-use hot cup is estimated to persist in the environment for about 30 years (WWF Australia, 2021).

Takeaway Cups (Cold)

Product Description

Cold cups are the single-use takeaway cups common at most cafes and restaurants. They are made from 100% plastic, but the type of plastic shows more variation than in hot cups.

Composition, Plastic Content, Type of Plastic

Cold cups are 100% plastic but can be made from different types of plastic. Cold cups may be made from PET, PLA, PP, or HDPE. Most of these can be recycled in Canada, but the plastic number and ease of recycling may differ between types. For example, HDPE is number 2 plastic, but PP is number 5 plastic. Cold cups are also sold in a wide variety of sizes that are inconsistent from one brand to the next. This can make estimating weights and volumes of waste challenging because there is low consistency from one cup to the next.

Volume of Waste

Canadians throw away an estimated 1.6 billion single-use plastic cups each year (Circulr, n.d.).

What Happens to the Waste?

The majority of plastic cold cups are recyclable in most places in Canada, but consumers often don't dispose of them in the correct bin. In those cases, they end up in landfills or as litter. Estimates are that only about 9% of these cups get recycled (Circulr, n.d.). In cases where they are properly recycled, the cups can be sold for profit to manufacturers of various goods.

Years It Persists in the Environment

Cold cups persist in the environment for up to 500 years (Circulr, n.d.).

Foam Trays

Product Description

Foam trays, also known as Styrofoam trays, are a product used for packaging food, typically at supermarkets. They are commonly used for products like meat, fish, and pre-cooked items. These trays do not have lids on them, so they are typically sold with the food on top being secured to the tray using plastic cling wrap.

Composition, Plastic Content, Type of Plastic

Foam trays are made of expanded polystyrene (EPS), sometimes known as Styrofoam, which is a number 6 plastic. The trays are made entirely of this material. Foam trays vary in size, but the most commonly used ones weigh 28–57 g, according to sales pages on Amazon (2026).

Volumes of Waste

Each year, Canada produces nearly 135,000 tonnes of single-use EPS material. This material cannot be recycled or reused.

What Happens to the Waste?

EPS is typically not recyclable in Canada, so all foam trays end up in landfills or as litter.

Years It Persists in the Environment

There are no firm estimates of how long foam trays persist in the environment, but estimates are in the hundreds of years, ranging up to over 500 (Davis, 2019).

Cigarette Butts

Product Description

Cigarettes are a tobacco product widely used by people around the world. Cigarettes were first introduced to Canada in the 1880s and became largely popular and socially normalized in the 1930s. In the 1950s, medical reports linked smoking cigarettes to lung cancer, which triggered the sales of cigarettes with added filters. As of 2022, 10.9% of Canadians aged 15 years and older smoke cigarettes, which is around 3.5 million Canadians (Health Canada, 2022). Prevalence of smoking is lowest in British Columbia (8.7%) and highest in New Brunswick (15.8%) (Health Canada, 2022). A total of 16 billion cigarettes were sold in Canada in 2023 (Health Canada, 2024).

Composition, Plastic Content, Type of Plastic

Cigarettes are composed of tobacco, chemical additives, a filter, and paper wrapping. There are 600 ingredients in cigarettes, and when burned, cigarettes release over 7,000 chemicals, 70 of which are known carcinogens. The filters in cigarettes are advertised to remove harmful irritants and impurities; however, the filters themselves are composed of cellulose acetate, a toxic plastic. The filters in cigarettes are made from bundles of thin hair-like fibres of cellulose acetate, a toxic plastic product that is non-biodegradable. The cigarette filter weighs approximately 0.114 g and accounts for about 13% of the total weight of a cigarette (Shahzad et al., 2022).

Volumes of Waste

The ends of cigarettes encasing the filter (cigarette butts) are often discarded improperly and are the most common type of litter found on Earth (Ocean Conservancy, n.d.; U of T Trash Team, n.d.). Each filter is made up of over 15,000 individual strands of synthetic microfibres, and 300,000 tons of these microfibres are released into the environment globally each year (Belzagui et al., 2021). In Canada, 5,338 tons of waste is produced from cigarette butts annually (Physicians for a Smoke-Free Canada, 2020).

What Happens to the Waste?

Governments are responsible for managing waste and environmental pollution and bear the economic burden of these direct and indirect costs. The actual amount of cigarette butts discarded or littered is unknown; however, based on surveys, half of smokers in the United States reportedly throw cigarette butts on the ground (Physicians for a Smoke-Free Canada, 2020). Cigarette butts are slow to degrade and leach toxic chemicals into the environment, threatening wildlife (Dobaradaran et al., 2021). Estimated costs due to cigarette waste are approximately USD 26 billion in the United States, and there are even higher costs associated with ecosystem losses upwards of USD 186 billion over 10 years (Sy, 2023).

Years It Persists in the Environment

Depending on conditions, cellulose acetate fibres in cigarette butts can last up to 30 years in the environment (Belzagui et al., 2021). It should be noted that even after the plastic has disintegrated in the environment, very small particles may exist in perpetuity.

Single-Use Vaping Devices

Product Description

A vaping device is a product originally intended to mimic cigarette use. It is battery-powered and works by heating a liquid containing nicotine, flavouring, and other chemicals into an aerosol. The user inhales the aerosol as if they are smoking. Most vaping devices consist of three main parts: a battery, a heating surface, and a cartridge or reservoir containing the liquid. There are many types of vaping devices, but they can generally be divided into two categories: single-use and reusable. A reusable vaping device would require the user to buy cartridges of liquid that can be changed out, while a single-use option would come with liquid inside it already and gets thrown away when the liquid runs out.

Composition, Plastic Content, Type of Plastic

Vaping devices are electronics, which means that in addition to plastic, they also contain metal components and batteries. In a single-use vaping device, all these components would be fused together, meaning they remain a single unit when the consumer throws it away. The type of plastic varies between different brands or models, but the most common plastics in these devices are ABS, PC polycarbonate, and PCTG (glycol-modified polycyclohexylenedimethylene terephthalate) (ALD Vapor, 2024). The weight of a vaping device can be extremely variable depending on brand and model (180Smoke, 2026).

Volume of Waste

There are currently no estimates as to how many single-use vaping devices are disposed of in Canada each year. There is survey data reporting that 1.5 million Canadians report using a vape in the last 30 days, and 721,000 report daily use (University of Waterloo, 2020).

What Happens to the Waste?

Vaping device disposal is dangerous because of the battery, but over half of vape users in Canada throw their old devices in the landfill ("Why disposable vapes," 2023). Only 15% report bringing their old vapes in for proper electronic recycling (CBC News, 2023). Any product disposed of that contains a lithium battery can pose a potential fire hazard during waste processing.

Years It Persists in the Environment

Estimates of how long vaping products persist in the environment are not available.

Vaping Device Cartridges

Product Description

A vaping cartridge is a small liquid-containing cartridge that can be inserted into a reusable vaping device. The liquid contains nicotine, flavouring, and other chemicals.

Composition, Plastic Content, Type of Plastic

A typical vaping cartridge weighs 1 g and is made of a combination of glass, metal, and sometimes, but not always, plastic. When they do contain plastic, it is not the primary material.

Volume of Waste

There are currently no estimates of how many of these cartridges Canadians dispose of each year.

What Happens to the Waste?

Cartridges are typically disposed of via landfill, as they do not contain a battery.

Years It Persists in the Environment

No estimates are currently available for how long these cartridges persist in the environment.

Tampon Applicators

Product Description

A tampon applicator is the outer device used to ease the insertion of a tampon. They can be made of either cardboard or plastic, but for the purposes of this research, we will be only interested in the plastic applicators. These applicators are meant to be disposed of in the garbage and are never recyclable due to their contact with bodily fluids. Sometimes, they are disposed of incorrectly by flushing them down the toilet.

Composition, Plastic Content, Type of Plastic

Tampon applicators are fully plastic, typically polyethylene or polypropylene. More recently, some tampon brands are experimenting with biodegradable plastics, but these are not the mainstream option. Although the types of plastic used in applicators are normally recyclable when used in other products, they are not recyclable as tampon applicators due to contact with bodily fluids.

Volume of Waste

Very little robust data is available on the volume of waste from tampon applicators, which may have to do with cultural taboos around periods. But estimates have been made based on the results of shoreline cleanups. About 2,800 tampon applicators are recovered during shoreline cleanups each year (Raman-Wilms, 2020). These represent almost entirely tampons that were flushed down the toilet (Raman-Wilms, 2020), so the total number would be much higher. Also, even among flushed applicators, most of them are handled at sewage treatment plants, so the ones coming up in shoreline cleanups are just a fraction of flushed applicators (Raman-Wilms, 2020).

What Happens to the Waste?

Tampon applicators should be sent to a landfill, and are sometimes flushed down toilets. But no estimates exist of how often applicators are disposed of incorrectly. Tampon applicators that are flushed down toilets will eventually end up in sewage treatment plants and sometimes on shorelines (Raman-Wilms, 2020).

Years It Persists in the Environment

Tampon applicators last for over 500 years in the environment (Borunda, 2019).

Appendix B. Wastewater Questionnaire Template

Survey Invitation: Single-Use Plastics in Canada's Wastewater Systems

IISD
International Institute for Sustainable Development

This project is funded in part by the Government of Canada
Ce projet est financé en partie par le gouvernement du Canada

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Single-use plastics (SUPs) are ubiquitous and often improperly disposed of, leading to significant environmental and municipal challenges.

The International Institute for Sustainable Development (IISD) is seeking your help to gather information on the most prevalent SUPs in the wastewater system as part of a larger project funded in part by Environment and Climate Change Canada (ECCC). This project examines the municipal and environmental costs of a series of SUP items (such as wet wipes, plastic bottles, cups, cigarette butts, foam trays, and plastic tampon applicators) in Canada.

Your assistance in identifying the most problematic items and the costs associated with them will be invaluable. It will help provide evidence of plastic-related wastewater infrastructure costs in Canada and address critical data gaps needed for potential education campaigns, corporate engagement, and policy strategies to tackle the significant issue of SUPs in our cities and environment.

Please respond to this 20 minute survey by November 30th, 2025.

We will be looking to collect details about your wastewater treatment system, including its location, types and frequency of SUPs encountered, removal and treatment methods, and associated costs. We'd appreciate if you could highlight any problematic SUPs and related incident impacts or costs. Best estimates are welcome, if audit data is unavailable, with any caveats noted.

Your responses will be linked to your city and shared with ECCC but will not be disclosed publicly. Insights will be presented only in aggregated form in the final public report and the final report shared with you when published.

Thank you for contributing to this important work!

Survey Invitation: Single-Use Plastics in Canada’s Wastewater Systems

Part 1. About your wastewater management system

* 1. Where is your system located? Specific city/town or community in Canada?

* 2. Which of the following best describes your wastewater management system?

- ◯ Municipal system (operated directly by city/town/regional staff)
- ◯ Municipal system (operated by a private company under contract/P3)
- ◯ Municipal utility corporation (arm’s length, publicly owned, e.g. Halifax Water, EPCOR)
- ◯ Industrial facility with its own wastewater treatment
- ◯ Indigenous community system
- ◯ Other (please specify)

* 3. How many wastewater treatment facilities do you manage or operate?

* 4. Approximately how many people or equivalent population does your system serve?

* 5. What types of wastewater do you treat?
(Check all that apply)

- ☐ Domestic/municipal
- ☐ Industrial
- ☐ Stormwater (combined sewer)
- ☐ Other (please specify)

Survey Invitation: Single-Use Plastics in Canada’s Wastewater Systems

Part 2. Single Use Plastic Items in Your Wastewater

* 6. Please indicate which single-use plastic (SUP) items end up in the wastewater management system of your municipality, and how often you encounter them.

Frequency scale:

No = Never observed
Rarely = < 1 time per month
Sometimes = 1–3 times per month
Often = Weekly or more
No data = Not monitored / no information

	No	Rarely	Sometimes	Often	No data
Wet wipes	○	○	○	○	○
Tampon applicators	○	○	○	○	○
Sanitary pads	○	○	○	○	○
Dental floss	○	○	○	○	○
Cotton buds/swabs	○	○	○	○	○
Plastic packaging (eg: film, sachets)	○	○	○	○	○
Cigarette butts	○	○	○	○	○

Other single us item (please specify)

____

* 7. Has your municipality/utility ever conducted an audit or study on single-use plastics (or similar items) entering your wastewater system?

○ Yes
○ No
○ Not sure

8. If yes: Would you be willing to share the findings or data?

○ Yes
○ Maybe (requires further discussion/permission)
○ No

* 9. Do you collect data on the amount of single-use plastics (SUPs) removed from your wastewater system?

- ◯ Yes, measured data (quantified by weight, count, or % share)
- ◯ Yes, estimated data (based on staff observations or partial counts)
- ◯ Yes, both measured and observed data
- ◯ No, no information available

10. If yes, please provide any available data (approximate or exact) in the boxes below.

For each single use item, please provide the weight [kg/tonnes] or count, or another unit you use, along with the timeframe.

Example: *we remove 10 wet wipes from our wastewater system every day.* or: *we remove 1 kg of wet wipes from our wastewater system every month*. etc.

Total incidence of plastics in screenings	
Wet wipes	
Tampon applicators	
Sanitary pads	
Dental floss	
Cotton swabs/buds	
Plastic packaging (e.g., film, sachets)	
Cigarette butts	
Other (please specify)	
Other (please specify)	

* 11. How does your wastewater system handle single-use plastic items when they are removed from the system?
(Select all that apply)

- ☐ Landfilling
- ☐ Incineration/waste to energy
- ☐ Other (please specify)

12. Please provide an approximate total annual cost (CAD) for managing single-use plastics removed from your wastewater system.

13. If possible, indicate whether the above cost is primarily labour, equipment, or other costs

14. We would like to understand the potential additional costs associated with most problematic single-use plastics (e.g., wet wipes causing blockages). Please indicate the **type** of these special events, **frequency** (per month or year), and the estimated **cost** associated with the event (e.g., labour, equipment):

Blockages/wet wipes

Other (please specify)

Other (please specify)

Other (please specify)

Other (please specify)

* 15. If we need clarification on any of the responses you provided, please share contact information for a member of your team whom our research team can reach out to. Providing this information is optional, but it will help us ensure the accuracy if we have questions or needs clarifications about the data.

Name

Role/position

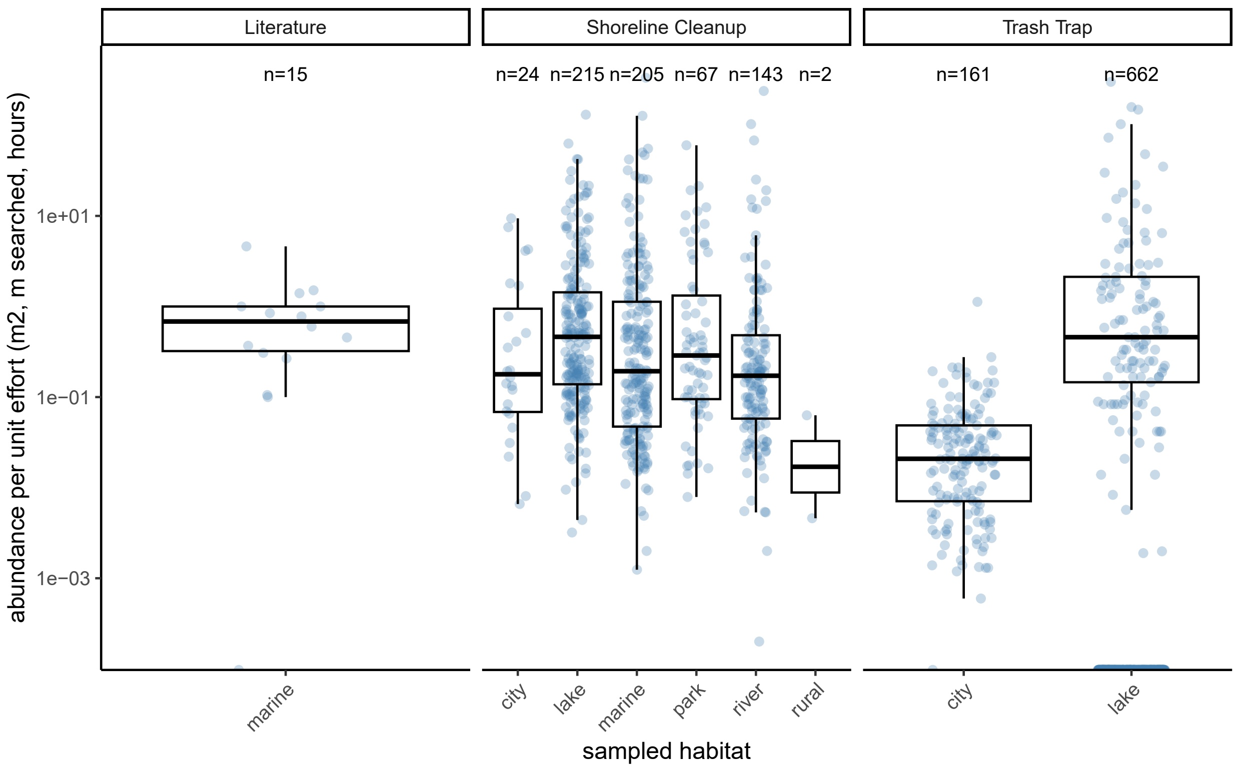
Email

16. Do you have any other observations or insights regarding single-use plastics in your wastewater system?

Examples: data gaps, challenges with collection or treatment, health and safety risks, or trends you've noticed, policy recommendations to address plastics in wastewater or any information that could be useful for policymakers.

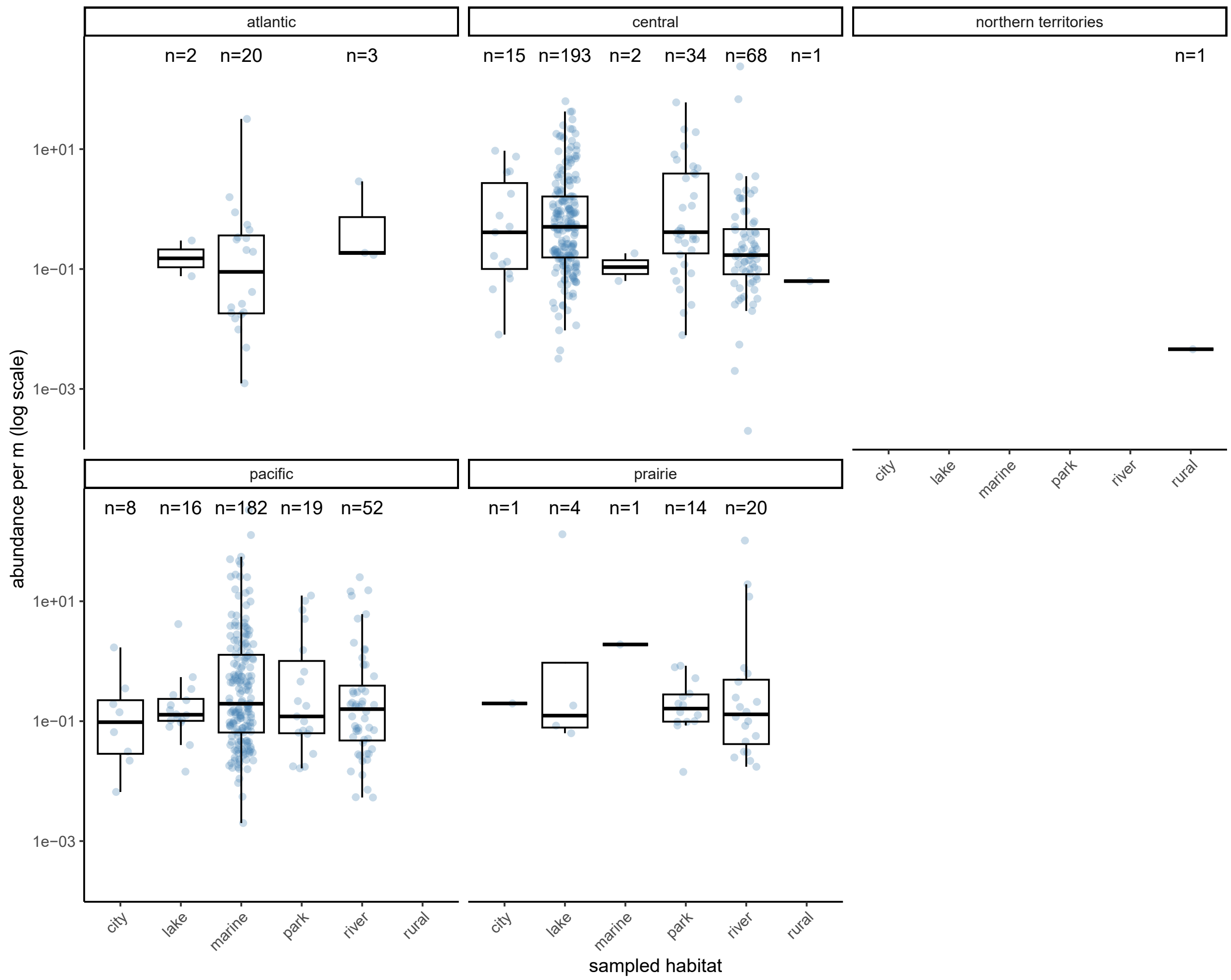
Appendix C. Abundance of Macroplastic and Single-Use Plastic Items Across Habitats and Regions in Canada

Figure C1. The abundance of macroplastics standardized by effort in different habitats across Canada



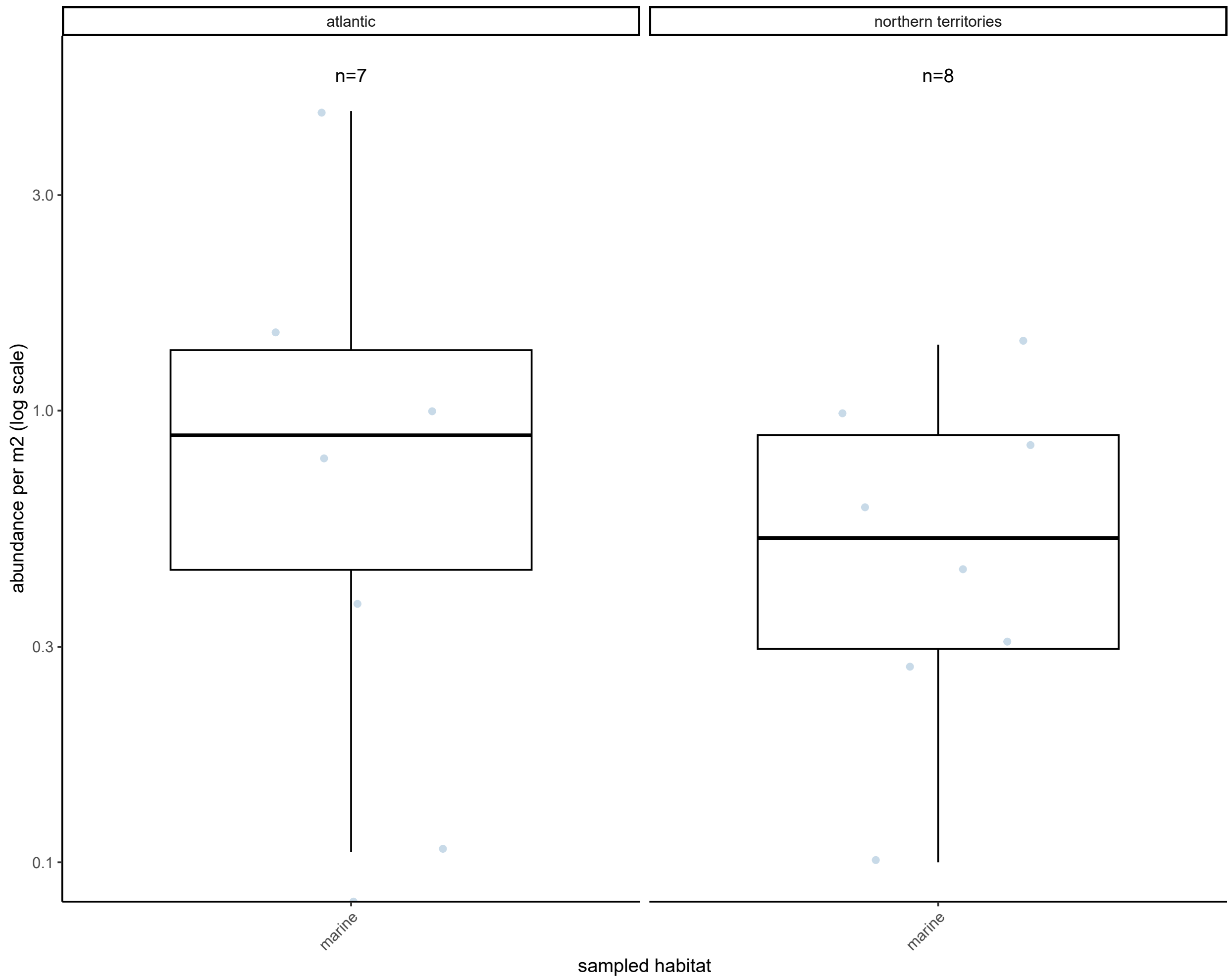
Source: Authors' diagram based on data from Ocean Conservancy, 2024 and Mallory et al., 2021.

Figure C2. Abundance of macroplastics across regions of Canada in sampled environment using cleanup data from TIDES



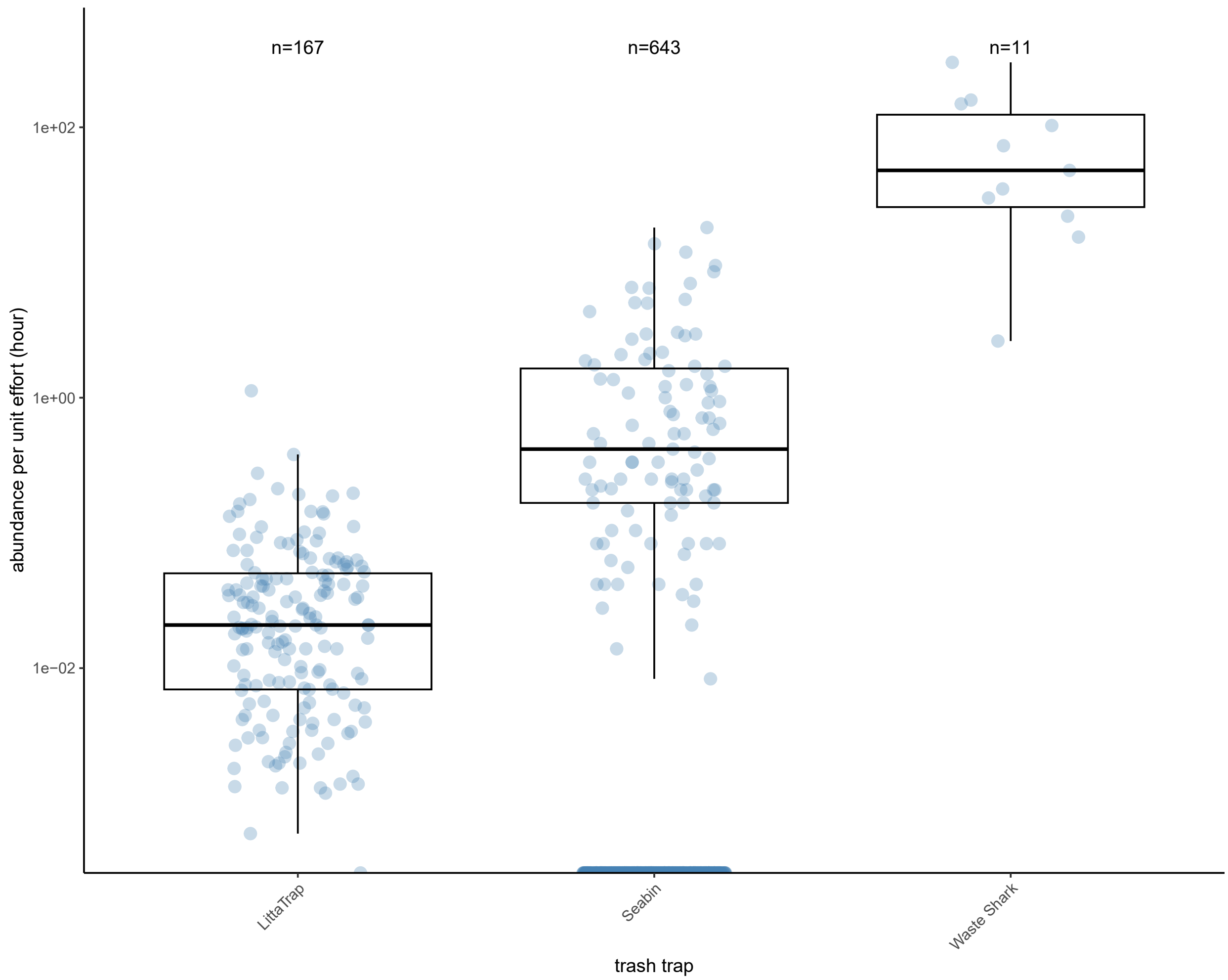
Source: Authors' diagram based on data from Ocean Conservancy, 2024 and Mallory et al., 2021.

Figure C3. Abundance of macroplastics across regions in Canada using data from Mallory et al. 2021



Source: Authors' diagram based on data from Ocean Conservancy, 2024 and Mallory et al., 2021.

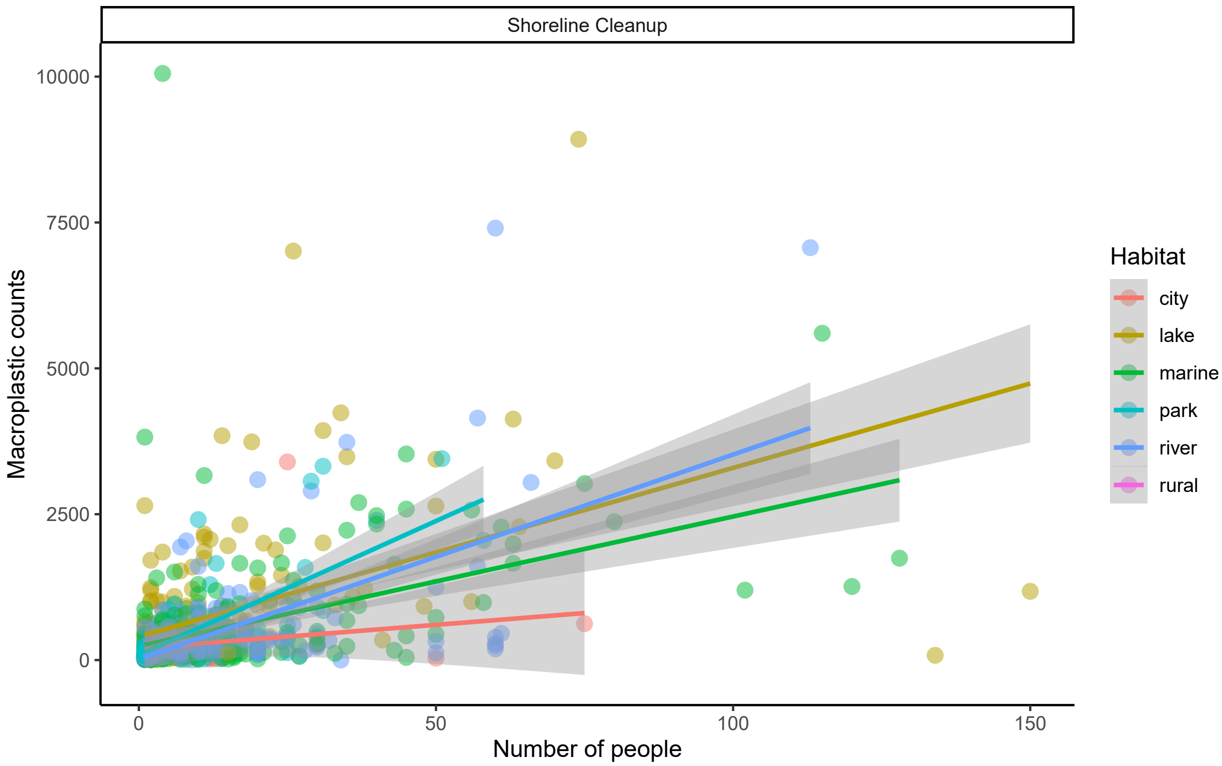
Figure C4. Abundance of macroplastic collected per hour from International Trash Trapping Network, litter traps located on land, seabins, and waste sharks located in freshwater marines



Note: All trash traps are located in Ontario, Canada.

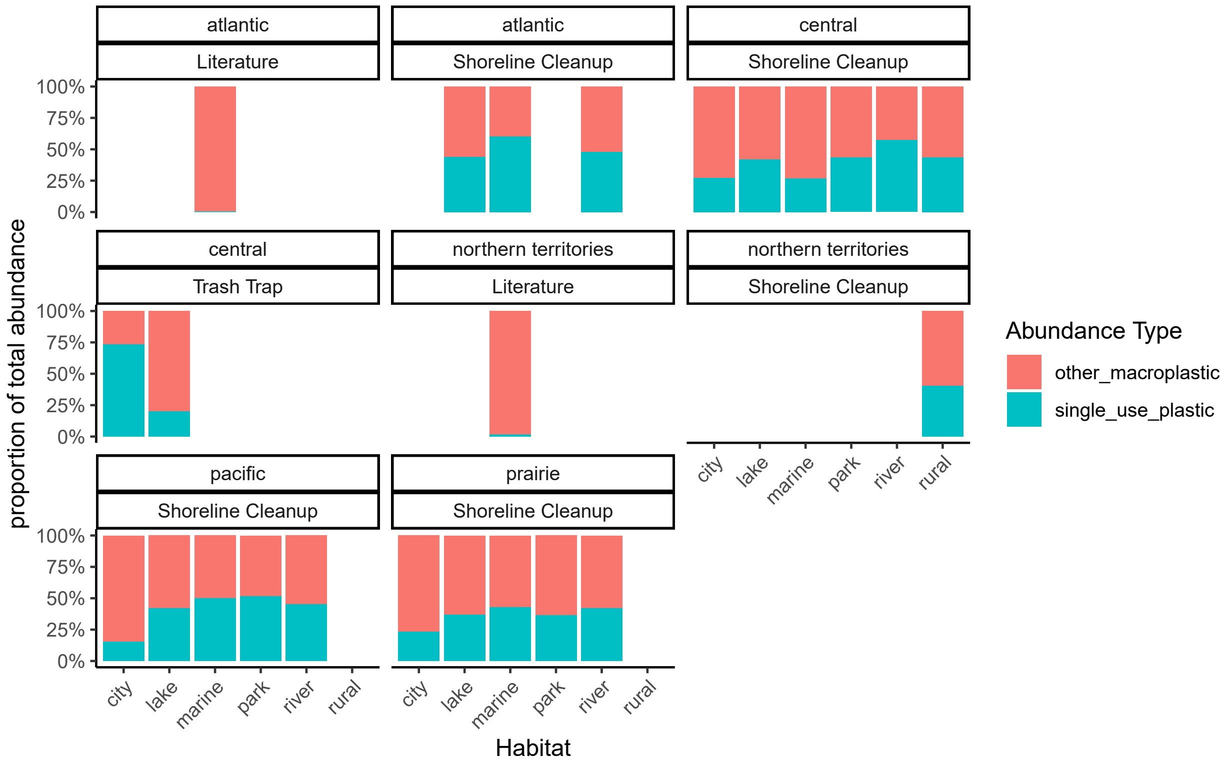
Source: Authors' diagram based on data from Ocean Conservancy, 2024 and Mallory et al., 2021.

Figure C5. Correlation between number of people at a cleanup and the amount of litter they collect



Source: Authors' diagram based on data from Ocean Conservancy, 2024 and Mallory et al., 2021.

Figure C6. Proportion of macroplastics classified as single-use vs. general macroplastics across regions in Canada and data sources (proportion derived from count estimates)



Source: Authors' diagram based on data from Ocean Conservancy, 2024 and Mallory et al., 2021.

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