Abundance and composition of microplastics in surface waters and sediments of five south-central Lake Ontario tributaries

by

Tammy Lynn Bleier

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Tammy Beier

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"All things are connected like the blood that unites us. We do not weave the web of life, we are a strand in it. Whatever we do to the web, we do to ourselves." -Chief Seattle

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ABSTRACT

More than 10,000 metric tons of plastic enter the Great Lakes every year. Most of this is microplastic, tiny plastic particles less than five millimeters in length or diameter. Microplastic pollution is a growing environmental concern in the Great Lakes where these particles can affect aquatic life as well as humans if ingested. To better understand potential sources of microplastics in Lake Ontario, we surveyed microplastic concentration in five tributaries within the south-central Lake Ontario basin in both surface waters and sediments. We analyzed the microplastic morphologies and polymer types and compared the results to three sites in nearshore south-central Lake Ontario. Tributaries surface samples had significantly higher microplastic concentrations (4.9 microplastics/m^3) compared to lake sites (1.3 microplastics/m^3). Tributary sediments had an average concentration of 0.16 microplastics/g dry weight. Fibers were the most common particle morphologies in tributary surface waters (49%) and sediments (52%) while fragments were the most common morphology found in lake surface waters (73%). These morphologies are harder for aquatic life to pass if ingested and are more likely to remain in the gut, leading to potential health issues and bioaccumulation in the food web. Polyethylene (recycling types two and four) and Other polymers (recycling type 7) accounted for over 90% of microplastics captured. Tributaries are important sources of microplastic pollution in south-central Lake Ontario and should be included in plastic prevention strategies. Furthermore, knowing the most prevalent morphologies and polymers may help to pinpoint sources of plastic and contribute to targeted prevention.

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INTRODUCTION

Global plastic production totals 348 million tonnes per year and is expected to increase (PlasticsEurope 2018). Plastic is created from oil, natural gas, and coal, and contains repeating chains of carbon and hydrogen fashioned into polymers. The most widely produced classes of polymers in production today are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC, Andrady 2011), most of which can be recycled. However, in the United States, only 8% of plastics generated are recycled, with an additional 16% of plastics recovered and combusted to be used for energy (EPA 2018). 76% of plastic generated in the US goes to landfills and the environment (EPA 2018). Plastics have been found in most ecosystems worldwide, including oceans, sediments, soils, air, lakes, and rivers. Plastic pollution is well-documented in marine systems, which currently contain 150 million metric tons (Mt) of plastic debris (McKinsey Center 2015). This is expected to increase to 250 Mt of plastic by 2025 (Jambeck et al. 2015). As of 2015, approximately 6300 Mt of plastic waste have been generated, of which 9% has been recycled, 12% incinerated, and 79% accumulated in landfills or the natural environment. If current production and waste management trends continue, roughly 12,000 Mt of plastic waste will be in landfills or in the natural environment by 2050 (Geyer et al. 2017).

Of the 150 million Mt of plastic in marine systems, approximately 250,000 Mt are microplastics (Eriksen et al. 2014). Microplastics are defined as plastic particles measuring five millimeters or less (Thompson et al. 2009). An estimated five trillion

microplastics are currently floating in the surface waters of the oceans (Eriksen et al. 2014). Even more microplastics may be deposited in marine sediments: 1.9 million microplastics were found in one square meter of seafloor off the coast of Italy (Kane et al. 2020). These tiny particles can be created via primary production or secondary production. Primary production is the intentional manufacture of microplastics, such as microbeads and pre-production pellets (also known as nurdles). Secondary production occurs when macroplastics (greater than 5mm in size) degrade in the environment, breaking into smaller pieces as they are exposed to wave action, UV light, erosion, temperature changes, and aquatic life. While plastic breaks down into smaller particles over time, it does not decompose for tens to hundreds of years. The only environmental factor known to instigate plastic decomposition is UVB radiation (Andrady 2011). Unless physically removed, microplastics remain in the environment and continue to degrade, creating more microplastics. Smaller particles, in particular microplastics, become more readily available to a wider range of aquatic organisms. Over 100 aquatic species are known to ingest plastic including birds (van Franeker and Law 2015), fish (Lusher et al. 2013), invertebrates (Taylor et al. 2016) and plankton (Kokalj et al. 2018). Organisms at the bottom of the food chain are likely to be important vectors of microplastics throughout their associated food webs. For example, if a prey fish has ingested microplastics and is then consumed by a predator, the predator can now retain the microplastics from the prey fish, creating bioaccumulation. Ingestion of microplastics can cause other adverse effects as well. The freshwater zooplankton, *Daphnia magna*, were immobilized after ingestion of

polyethylene particles (Rehse et al. 2016). Immobilization can lead to starvation, and ultimately death, as the plankton cannot properly filter particles for food. *Daphnia magna* readily ingested one µm particles but did not ingest 100 µm particles (Rehse et al. 2016), suggesting smaller microplastics may be more easily transferred within food webs. Algae and other natural food sources typically range from 0.7-70 µm for *D. magna*, so microplastics may be mistaken for food. Microplastics often accumulate a biofilm layer in the environment, making microplastics more attractive for consumption to filter feeders and grazers, though this has been shown to be dependent on the plastic polymer and typically produces sublethal effects such as inhibition of growth and reproduction (Michler-Kozma et al. 2021).

Microplastics can also sorb persistent organic pollutants (POPs) in the environment. Sorption includes both absorption, where compounds are taken into the interior structure of a polymer, and adsorption, where compounds adhere to the surface of a polymer. Degradation and breakdown of plastics can create a larger surface area, giving microplastics the ability to carry and release more chemical compounds than macroplastics. Several toxins are known to sorb microplastics including polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), heavy metals, and phthalates, among others. While not all these chemicals have toxic effects, many are known carcinogens, mutagens, and endocrine disruptors. Microplastics can increase concentrations of these chemicals by 10^5-10^6 times that of ambient water (Betts 2008), creating potentially toxic conditions. Furthermore, different types of plastic have higher affinities for certain compounds (Rochman et al.

2012). For example, PE and PP have higher affinities for PAHs and PCBs compared to PET and PVC. PVC was more likely to sorb alkylbenzenes than PP, while PE was found to have the highest affinity for both PCBs and PAHs (Rochman et al. 2012). In addition, plastic polymers are created with a variety of chemical compounds. They are inserted between the layers of hydrogen and carbon chains that constitute the foundation of each polymer. Flame retardants, plasticizers, colorants, and other compounds are added to plastics during the manufacturing process. If microplastics are ingested they can release both POPs and synthetic chemicals into the gut contents, potentially leading to toxicity depending on the type of plastic consumed and the POPs it has sorbed (Rochman et al. 2013). Toxin transfer increases the longer plastic particles remain in an organism (Andrady 2011) raising the potential for harmful effects.

While much attention has been paid to oceanic plastic pollution, there is a recent focus on freshwater systems. About 80% of marine plastic comes from land-based sources, much of which is transported via rivers and tributaries (Horton et al. 2017). Land-based plastic debris can be transported to waterways via stormwater runoff, landfills, textile laundering facilities, petrochemical plants, and wastewater treatment plants (WWTPs, Browne et al. 2011). On average, 13 billion microplastics are released daily from WWTPs in the United States and discharged directly to both marine and freshwater ecosystems (Mason et al. 2016). However, stormwater runoff may account for significantly more plastic transport to waterways than WWTPs (Liu et al. 2019).

Freshwater concentrations of microplastics have been found to rival those found in the marine environment. Driedger et al. (2015) assessed that the Great Lakes are as polluted as the worst parts of the world's oceans. More than one billion microplastics are in the surface waters of Lake Michigan alone (Mason et al. 2016). The Great Lakes are estimated to have more microplastics less than one mm in size compared to marine systems, which are more likely to have larger plastic particles (Driedger et al. 2015). This is due in part to an increased number of microbeads, which are intentionally manufactured to be less than one mm, in the Great Lakes compared oceanic samples (Eriksen et al. 2013, Moore et al. 2001). In terms of weight, nearly 10,000 metric tons of plastic pollution enter the Great Lakes every year (Hoffman and Hittinger 2017). Of this, 5,000 metric tons flow into Lake Michigan, 2,500 metric tons to Lake Erie, 1,400 metric tons to Lake Ontario, 600 metric tons to Lake Huron, and 32 metric tons to Lake Superior (Hoffman and Hittinger 2017). While Lake Ontario receives the third largest amount of plastic pollution by weight, it has the highest surface-level microplastic concentration of all the Great Lakes with an average of over 230,000 particles/km^2 or 0.23 particles/m^3 (Mason et al. 2020). Lake Ontario is the final Great Lake before entering the St. Lawrence River, which empties into the North Atlantic Ocean at the Gulf of St. Lawrence. Eventually, plastic pollution from the Great Lakes Basin will contribute to marine litter. It is therefore important to understand plastic pollution in the Great Lakes' basin for its own health, in addition to understanding implications for the oceans. Lake Ontario is also one of the least studied Great Lakes in terms of

microplastics. To date, only two published studies have explored microplastic concentrations in the surface waters of Lake Ontario (Grbić et al. 2020; Mason et al. 2020), while the other Great Lakes have been surveyed several times (Eriksen et al. 2013; Mason et al. 2016; Cable et al. 2017; Cox 2018; Hendrickson et al. 2018; Minor et al. 2020).

Because rivers and tributaries are important vectors of plastic pollution, it is necessary to understand their contribution to the Great Lakes. Baldwin et al. (2016) surveyed 29 Great Lakes tributaries and found higher microplastic concentrations compared to pelagic environments. Concentrations up to 32 microplastics/m^3 were recorded, most of which were fibers and lines (Baldwin et al. 2016). This is comparable to findings from similar studies conducted on the Seine River (Dris et al. 2015), Chicago River (McCormick et al. 2014), Danube River (Lechner et al. 2014) and four Chilean rivers (Rech et al. 2015). Tributaries with the highest microplastic concentrations were positively associated with urban areas, high population densities, or industrial use. However, Hovsgol Lake, located in a remote region of Mongolia, has shown high levels of microplastics (Free et al. 2014), suggesting that microplastic pollution occurs even in isolated areas.

While much attention has been given to surface microplastics, there is an increasing need to study microplastics in marine and freshwater sediments. Sediment microplastics are severely understudied, especially in the Great Lakes watershed. Corcoran et al. (2015) surveyed Lake Ontario sediments near Toronto, Ontario, and discovered that microplastics have been settling into the shallow benthos for

approximately 38 years. One hypothesis is that as plastic accumulates a biofilm in the environment, it becomes negatively buoyant and eventually settles into the benthos. Therefore, even positively buoyant polymers such as PE and PP are likely to reach the lake bottom. Tributaries, which have been found to contain greater microplastic surface concentrations than lakes, should therefore be analyzed for sediment concentrations as well. This is especially true of the Great Lakes basin, where microplastic surface concentrations rival that of marine environments. Furthermore, this could have a negative impact on benthic organisms. Species that feed from the substrate may be ingesting a significant amount of microplastics they are unable to pass, leading to starvation or even death. Many benthic species are consumed by species in higher trophic levels, leading to bioaccumulation of microplastics up the food chain. At least eight fish species, spread out across the food web, are known to consume microplastics (Munno et al. 2021).

Understanding microplastic types and distribution could inform policy decisions, potential sources, and removal methods. Most importantly, this information could be utilized to build prevention strategies: it is easier to prevent plastic from entering an ecosystem versus removing it from the environment. This study seeks to further our understanding of both surface-level and sediment microplastics in five Lake Ontario tributaries to recommend plastic pollution management strategies. We investigate the concentration and size distribution of microplastics in south central Lake Ontario and tributaries, hypothesizing that microplastics will be present at all lake and tributary sites and that tributary microplastic concentrations will be greater than lake

concentrations. In addition, we compare the number of microplastics captured between a traditionally used 333 µm net and an 80 µm net, predicting the latter will capture more particles. We also explore how microplastic concentrations vary among space, hypothesizing that Irondequoit Bay and Long Pond will have the highest microplastic concentrations at both surface and in sediments. Finally, we examine which morphological and polymer types are most common and how their distribution across sites, hypothesizing that lines/fibers will be the most common microplastic morphology and PE and PP will the most common polymers in all tributary and lake samples.

METHODS

Study Sites

We sampled five tributaries of varying land use in the south-central basin of Lake Ontario (Figure 1). Oak Orchard Creek was the westernmost site and is predominantly used for agriculture. It was the only site in Orleans County; the remaining sites were in Monroe County. Long Pond is downstream of a landfill that closed in the 1990s and is used as a recreational fishing site. Long Pond is also located in a highly residential area. Irondequoit Bay is the easternmost bay in Monroe County. While Irondequoit Bay is predominantly surrounded by forest, it is also heavily used for recreational purposes. The Genesee River flows 160 miles from Potter County, Pennsylvania, to Monroe County, New York, where it empties into Lake Ontario. It passes through a range of rural, suburban, and urban areas and is also used recreationally for boating and fishing. The Erie Canal does not flow directly to Lake Ontario, but connects to the lake through other tributaries, including Oak

Orchard Creek. Furthermore, the Erie Canal traverses New York State, connecting Lake Erie with the Hudson River, and may be a vector of microplastics to other water bodies. At the time of this publication, there is no published data on microplastics in the Erie Canal.

Three lake sites were sampled near Braddock Bay in Hilton, New York (Figure 1). The east site (LO East) was located 7.6 km from shore, the center site (LO Center) was located 5.0 km from shore, and the west site (LO West) was 2.9 km from shore. Each site was at least 4.0 km apart. The lake sites were approximately halfway between Oak Orchard Creek and Irondequoit Bay, the westernmost and easternmost tributary sites, respectively.

Surface Sampling

Tributary samples were collected from August to September 2018 and June to August 2019 for a total of 27 samples (total n = 45, Table 1). We collected tributary samples by suspending two plankton nets, each measuring one-meter in diameter, simultaneously from a bridge against the flow of water for approximately 15 minutes. One net had a mesh size of 333 µm, the standard size used for microplastic sampling, and the second net had a mesh size of 80 µm to capture smaller particles. We estimated the volume of water filtered using a flow meter affixed at the opening of both nets. The nets were deployed so that two-thirds of the net was submerged to maintain consistency of the depth sampled between sites. After 15 minutes, we rinsed the nets until all contents were in the cod end, then transferred the contents to pre-washed glass Mason jars. We thoroughly rinsed the nets and cod ends with distilled

water between each tow. Tributary samples were collected on the same day within each month to avoid potential differences in microplastic concentration due to changes in currents, weather, and other sources of plastic input.

We collected lake surface samples from June to August 2019 for a total of 18 samples (Table 1) using modified collection methods from Eriken et al. (2013). All sites were marked using GPS. We collected lake samples aboard the *RV Madtom* using two plankton nets measuring one meter in diameter. Each net was securely tied to the *RV Madtom* (25.5-foot research vessel, rigged with starboard and port booms) and deployed alongside the vessel to minimize any effects of the boat's wake and reduce contamination from the vessel. We marked the nets so that approximately two-thirds of the nets were submerged below the surface. Tows lasted 15 minutes. Boat speed was recorded to calculate the volume of water passing through each net. After 15 minutes, we followed the same procedure as the tributary samples for rinsing, collecting, and transferring samples to be stored until ready for microplastic separation and quantification. All lake samples were collected on the same day within each month.

Sediment Sampling

We collected sediments from Oak Orchard Creek, Long Pond, Genesee River, and Irondequoit Bay. Sediment samples were collected once a month from June to August 2019 and were collected within one day of tributary surface sampling. We did not collect sediment samples from Erie Canal, which has a hard bottom. We used a Wildco® Petite Ponar® Stainless Steel Grab for collection. Sampling sites were

marked with GPS. At each site, we deployed the ponar three times, once at the GPS marked spot, once one meter to the right, and once one meter to the left. We then mixed the contents in a one-gallon bucket and covered it with aluminum foil. Upon returning to the lab, we transferred a subsample of 400 g of sediment from each site to a dry, pre-weighed 800 mL beaker and covered with foil. We dried the sediment at 70ºC for 24 hours, let it cool, and reweighed the beaker (Masura et al. 2015). We returned the beakers to the oven at 70ºC for another 24 hours, reweighed, and proceeded if the weight was consistent within 5%. Two samples broke during laboratory processing, one from Genesee River and one from Oak Orchard Creek, for a final total of 10 samples (Table 1).

Microplastic separation and quantification

Surface Samples

Wet peroxide oxidation (WPO)

To begin isolating microplastics, we first removed large organic matter from each sample using a 333 µm sieve. We rinsed all material greater than 333 µm into the original Mason jar containing the sample to capture microplastics that may have adhered to large debris. Large plastic pieces were rinsed, removed, and recorded. Next, we added 20 mL of aqueous 0.05 M Fe(II) solution to each sample, which catalyzes the breakdown of organic debris (Masura et al. 2015). We then added 20 mL of 30% hydrogen peroxide to the samples; this reacts with the aqueous 0.05 M Fe(II) solution to further catalyze the breakdown of natural debris (Masura et al. 2015). More hydrogen peroxide was added in 20 mL increments if the sample did not

begin to bubble (Masura et al. 2015). We left the samples in a fume hood for 12 hours for the reaction to breakdown remaining organic debris. If any organic matter remained after 12 hours, we repeated the process a second time.

Density separation

We transferred the WPO solution to pre-rinsed one-liter separatory funnels. Mason jars were thoroughly rinsed with distilled water to capture all remaining solids and transferred to the funnels. Next, we added density separation solution, aqueous zinc chloride, at a 1:1 sample to solution ratio. The aqueous zinc chloride was made at a density of 1.6 g/cm^3 to capture heavier polymers like PVC and PET, which both have densities of 1.4 g/cm^3. We covered the separatory funnels with aluminum foil to avoid contamination of the sample and stirred to mix the density separation solution and WPO solution. After letting the mixture settle for ten minutes, we stirred it again. This was repeated twice more to ensure thorough mixing and capture of microplastics. We left the solution to settle for one hour then drained the bottom layer off and discarded it. The top layer, containing any plastic debris, was drained into a glass beaker. We rinsed the separatory funnels with distilled water to remove any remaining solids. We then filtered the solution containing the top layer using a vacuum pump onto glass fiber GF/C filters. For samples with a high number of microplastics, several filters were used to avoid particle overlap and therefore more accurate counting. We placed filters in labeled aluminum tins and stored them in a glass desiccator until ready for count analysis.

Sediment Samples

We added 300 mL of aqueous zinc chloride (specific density 1.6 g/cm^3) to the beaker and stirred the mixture for 15 minutes with a metal spatula (modified from Masura et al. 2015). We covered the mixture with aluminum foil and allowed it to settle overnight. We then decanted the liquid through a 100 µm sieve, transferred the particles from the sieve to a clean beaker, and added the liquid back to the sample. This was repeated two more times to ensure any microplastics in the sample were captured in the decanted layer. After the third decanting, we discarded the zinc chloride and rinsed the sieve's contents into the new beaker. We then processed any remaining organic material using WPO and vacuum filtered the microplastics onto glass microfiber GF/C filters.

Count and polymer analysis

We used a Wild Heerbrugg M5 stereo microscope to count plastic particles. We categorized microplastics into five categories based on particle morphology: fibers/lines, beads, foams, fragments, and films. We used the 20x lens to quantify plastics on each filter and record the total number in each sample. The ocular lens contained 2.5x magnification for a total magnification of 50x. Five samples (10% of total samples) were recounted to verify that the original counts and categorizations were accurate. Categorization and counts varied by less than 5%.

Plastic particles were further analyzed using Raman spectroscopy for polymer type. We used a WITec Alpha300R Confocal Raman Microscope at the Cornell Center for Materials Research (CCMR) to analyze polymer composition. Raman spectroscopy relies on a high intensity laser light source to detect photons emitted

from the particles being analyzed. This emits a radiation signal whose wavelength is measured as a spectrum of peaks. We used Control 5.2 Software for Raman Spectroscopy from Renishaw to capture and analyze the spectra. We then uploaded the signals to KnowItAll(R) Informatics System 2018 Academic Edition, where the spectra were compared to those stored in the KnowItAll database to identify the polymer composition. We used a threshold of 85% matching between particle signals and database signals. Polymers were placed into six categories: polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), and Other, which encompasses all other plastic polymers. These correspond to the most common polymers in production worldwide as well as the numbering system for recyclable plastics in the United States (Table 2). Tributary and lake surface samples from August 2019 were analyzed from each tributary and lake site and included one sample captured using a 333 µm net and one from the 80 µm net. In August 2019, tributary and lake samples were taken only one day apart, on August 6 and 5, respectively. This was the shortest time in between sampling surveys, minimizing the potential of storm runoff or other environmental factors from impacting polymer composition. We analyzed 117 microplastics from surface samples and 15 microplastics from sediment samples for a total of 132 plastic particles.

Cross-contamination controls

All glassware was pre-washed in a 10% HCl bath and pre-rinsed with dichloromethane (DCM). We used glass and metal materials instead of plastic

materials whenever possible. Plankton nets were washed between individual sample collection and soaked in a soap bath and rinsed with distilled water after daily use. We noted the color of the rope used during sampling and recorded the same color microplastics in any samples. Wet samples were stored in covered glass or metal containers under a fume hood, and filters were stored in a covered glass desiccator. We administered density separation and WPO under a fume hood and wore cotton lab coats to reduce microfiber contamination from clothing. We tested distilled water in the laboratory for microplastics using the same methods outlined above and found no plastic particles greater than 100 µm.

Data Analysis

We used Microsoft Excel to relativize all microplastic concentrations, including both morphology and polymer data. To relativize surface sample data, we divided the number of microplastics by the volume of water collected in that sample, resulting in units of microplastics/m^3. For sediment samples, we divided the microplastic count by the dry weight of the associated sample, resulting in units of microplastics/g dry weight.

To assess the concentration and size distribution of microplastics in south central Lake Ontario and tributaries, we represent the data with boxplots with Site on the x-axis and microplastics/volume on the y-axis, where the minimum concentration, maximum concentration, median concentration, and first and third quartiles of the range of concentrations are shown for each site. We achieved normality of the microplastic concentrations between the nets using a square root transformation, and

therefore used a paired t-test where concentrations were averaged within each site across month to assess the difference in microplastics captured between the nets. To compare microplastic concentrations between tributary and lake sites, we analyzed concentrations from the 333 µm net using the Kruskal-Wallis test. We used a threshold of alpha less than or equal to 0.05 when reporting significant differences in microplastic concentrations.

We were not able to achieve normality of the data and therefore used the Kruskal-Wallis test followed by the pairwise Wilcoxon test with continuity correction and the Benjamini-Hochberg p adjustment as a post hoc to determine which sites had significantly higher microplastic concentrations. We used a threshold of alpha less than or equal to 0.05 when reporting significant differences in microplastic concentrations.

We created a stacked barchart with site on the x-axis and number of microplastic percent abundance on the y-axis to determine which morphological and polymer types were most abundant among sites. We used non-metric dimensional scaling (NMDS) ordination to represent these data and show relationships among site, month, and morphological type and among site, month, and polymer type. We used a scree plot to determine the best number of dimensions to use while minimizing stress to 0.2 or less. In addition, we ran a principal component analysis (PCA) to further explore the relationship between site and polymer morphology.

We used Microsoft Excel to calculate all averages, standard deviations, percentages, barcharts, and boxplots. We used R Studio (R Core Team 2020) to test

for normality of all data using the Shapiro-Wilk test, to calculate all Kruskal-Wallis and Wilcoxon tests using the dplyr package (Wickham et al. 2020). PRIMER 6 was used to create the NMDS plots, which used the Bray-Curtis dissimilarity index, as well as the PCA.

RESULTS

Microplastic concentrations and size distribution

Surface samples

A total of 3,374 microplastics were found among all surface samples. Overall, tributaries had a higher surface concentration of microplastics than lake samples, with average concentrations of 4.9 (SD = 4.9) and 1.3 (SD = 1.5) microplastics/m^3, respectively (Figure 2). Irondequoit Bay had the highest concentration of surface microplastics (mean = 6.3 microplastics/m^3, SD = 7.9), followed by Erie Canal and Oak Orchard Creek, both with average concentrations of 4.9 microplastics/m^3 (SD = 5.0 and 4.6, respectively). Long Pond's concentration was roughly half that of Irondequoit's at 3.8 microplastics/m^3 (SD = 2.2). The average concentration among lake sites were 0.7 (SD = 0.7), 1.2 (SD = 0.9), and to 2.1 (SD = 2.4) microplastics/m^3 for Lake Ontario West, Lake Ontario Center, and Lake Ontario East, respectively, with concentration increasing from west to east. Microplastic concentration variations across time showed a similar pattern for both lakes and tributaries, where concentration decreased in July 2019 followed by an increase in August 2019 (Figure 3). Tributaries averaged 0.89 microplastics/m^3 in June 2019, decreased to 0.35 microplastics/m^3 in July, and increased to 1.44 microplastics/m^3 in August 2019.

Lakes had lower concentrations from June – August 2019 with average concentrations of 0.17, 0.06, and 0.49 microplastics/m^3, respectively. Overall, tributaries showed higher concentrations in 2019 compared to 2018, with August 2019 showing the highest concentration in both tributaries and lake sites (Figure 3).

The 80 µm net captured a slightly lower average of 2.8 microplastics/m^3/sample (SD = 3.9) compared to 3.5 microplastics/m^3/sample (SD = 3.5) captured in the 333 µm net, though this was not a significant difference ($p=0.57$, df = 18, t Critical two-tail = 2.1) (Figure 4). Particle size was analyzed for the August 2019 microplastics and ranged between 100 and 5000 µm among all samples collected, with an average particle size of 1881.3 µm. Tributary particle size averaged 573.2 µm compared to an average lake particle size of 2146.8 µm.

Sediment samples

We found 375 microplastics among all sediment samples. Average sediment concentrations ranged from 0.02 to 0.28 microplastics/g dry weight with an average concentration of 0.16 microplastics/g dry weight (SD = 0.22) among all sites (Figure 5). Long Pond had the highest average microplastic concentration among all sites (0.28 microplastics/g dry weight) followed by Irondequoit Bay (0.16 microplastics/g dry weight), Genesee River (0.13 microplastics/g dry weight), and Oak Orchard (0.02 microplastics/g dry weight) (Figure 5). While Oak Orchard had the second highest microplastic concentration among surface samples, it had the lowest concentration among sediment samples. In contrast, Long Pond had the highest sediment

concentration of microplastics while being one of the tributary sites with the lowest surface-level microplastic concentrations.

Particle morphology distribution

Surface samples

Fibers (49%) and fragments (36%) were the most common plastic morphologies found at surface-level in tributaries while fragments were most common among lake surface samples (73%) (Figure 6). Films and foams were the least common microplastic types found among lake sites, 2% and 1% respectively. In tributaries, beads (4%) and films (1%) were the least common. All morphologies were found at each lake site, while some morphologies were not found in each tributary. Tributary sites showed more variation in the types of microplastics they contained (Figure 6). For example, 60% of microplastics from Erie Canal were beads. The site with the next highest proportion of beads was Oak Orchard, where they represented less than 10% of microplastics found.

Two morphologies showed significantly different concentrations among sites: beads ($\chi 2$=13.6, df=6, p=0.03) and fibers ($\chi 2$=13.8, df=6, p=0.03). However, post-hoc tests did not show significant differences in the concentrations of these morphologies between sites (Figure 7). Fragments, foams, and films showed no meaningful difference between sites (Figure 7). Concentrations of plastic morphologies were similar within lake sites while tributary sites showed more variation in their morphologies (Figure 8). Long Pond and Oak Orchard were more similar to lake sites compared to Erie Canal and Irondequoit Bay (Figure 8). Fibers and beads showed the

strongest relationship with site (eigenvectors = 0.79 and 0.78, respectively) and were more abundant in tributaries (Figure 9). Fibers were especially abundant in samples collected from Oak Orchard in August 2018 with the 80-µm net and from Irondequoit Bay in August 2018, also with an 80-µm net, while a sample from Long Pond in August 2019 using a 333-µm net had an especially high concentration of beads. Fragments, foams, and films had very weak relationships (eigenvector = 0.16, 0.24, and 0.16, respectively) (Figure 9).

Sediment samples

Fragments and fibers were the most common morphologies among sediment samples (Figure 10). Fragments comprised at least 50% of the microplastics found at each site except Oak Orchard, where the only type found was fibers. Films accounted for less than 5% of microplastics found at each site; Genesee River had the highest concentration (Figure 11). Irondequoit Bay was the only site to contain beads (Figure 11). Long Pond had the highest concentration of both fragments and fibers (Figure 11). No foams were found in sediment samples. There was no significant difference in morphology concentrations among sites. There was no clear pattern in morphology type distribution among sites (Figure 12).

Polymer distribution

Surface samples

The most common polymer among all surface samples was polyethylene (49%) (Figure 13). The second most common polymer category overall was Other (39%). Approximately 8% of particles from surface samples were not classified as

plastic. Plastic, mainly polyethylene, was detected in most of these particles but were below the 85% threshold and therefore were not included as plastic. A few particles were not detected as plastic at all, most of which were organic carbon compounds. The remaining 4% was comprised of polypropylene, polystyrene, and polyvinyl chloride. No polyethylene terephthalate was found in any of the surface samples.

The most common polymer among tributaries was Other (49%) (Figure 13). Many of these other polymers were cellulose acetate and copolymers containing mixtures of several polymers, often including polyethylene. The next most common polymer was polyethylene (41%) (Figure 13). There were no clear patterns among polymer concentrations among sites (Figure 14). No polystyrene, polyvinyl chloride, or polyethylene terephthalate were found in any tributary samples (Figure 15).

All polymers except polyethylene terephthalate were found in lake samples (Figure 16). Polyethylene was the most abundant, accounting for 80% of the lake surface samples. Polyvinyl chloride accounted for 5% of polymers in lake samples, followed closely by Other at 4%. Less than 1% each was found of polypropylene and polystyrene. Approximately 9% of lake samples were not plastic. There was no significant difference in polymer concentrations among lake or tributary sites.

Sediment samples

Only three polymer categories were discovered in tributary sediment samples: Other (91%), polyethylene (5%), and non-plastic (4%) (Figure 17). Polyethylene was found in Genesee River and Long Pond sediments. Non-plastic particles were found in Irondequoit Bay and Long Pond. Other plastic polymers were discovered at all

sites. Most of these were copolymers and cellulose acetate, as seen in surface samples. Many of the copolymers contained polyethylene.

DISCUSSION

Microplastic concentrations and size distribution

Microplastics were found in all samples among all sites, both surface and sediment, supporting my hypothesis that microplastics would be found in all lake and tributary sites. My hypothesis that microplastics less than 333 µm would be the most abundant was not supported: the average particle size in lake and tributary samples was 2146.8 µm and 573.2 µm, respectively, though size was only analyzed in a very small subsample of particles from August 2019. Our findings differ from Eriksen et al. (2013), where most plastics found in the Great Lakes were less than 1000 µm. Similarly, Mason et al. (2020) found 73% of microplastics from Lake Erie and Lake Ontario were in the 335-999 µm size range. These dissimilarities may be due to differences in sampling sites. Both Eriksen et al. (2013) and Mason et al. (2020) sampled throughout the Great Lakes over a longer time scale, whereas I focused my samples in one region of Lake Ontario over a shorter time. This suggests that microplastics entering the south-central region of Lake Ontario may be larger compared to inputs from other parts of the lake.

In addition, there was no significant difference (paired two-sample t-test, $p=0.57$) in the number of particles captured between the two nets: the 333- and 80-µm nets captured an average of both of which captured an average of 3.5 and 2.8 microplastics/m^3/sample, respectively (Figure 3). This may be attributed to backflow

from the 80 µm net; the smaller the pore size, the more resistance there is to water passing through the net, creating backflow and potential loss of particles.

Most of the microplastics we analyzed were fragments and fibers, which are secondary microplastics, indicating that these particles may not have been in the environment long enough to breakdown into smaller particles. This region could be an important source of larger microplastic input and should be studied further to pinpoint potential sources.

The tributaries had a significantly higher mean concentration of microplastics (4.9 particles/m^3) compared to lake samples (1.3 particles/m^3), supporting my hypothesis that tributary concentrations would be greater than lake concentrations (Figure 2). Baldwin et al. (2016), who found higher microplastic concentrations in 29 Great Lakes tributaries compared to pelagic sites, further support this hypothesis. Baldwin et al. (2016) found an average of 4.2 microplastics/m^3 among the tributaries in their study, reflecting a similar concentration of microplastics in tributaries of south-central Lake Ontario.

Our findings of 1.3 particles/m^3 are much higher than those of Mason et al. (2020) who found an average of 0.23 particles/m^3 in Lake Ontario. The difference may be due to sampling sites: Mason et al. (2020) focused on pelagic Lake Ontario whereas our lake samples were much closer to shore, indicating microplastic concentration may decrease further from shore. Our findings are more similar to concentrations found in Lake Mead National Recreation Area, where surface microplastic concentrations ranged from 0.44-9.7 particles/ m^3 (Baldwin et al. 2020).

Similar to my study sites in Lake Ontario, Lake Mead receives WWTP effluent from a tributary, is heavily used for recreational purposes, is fed by a major river that runs through predominantly agricultural and rural land use and is a source of drinking water for millions of people. The Rochester embayment may reflect microplastic concentrations similar to the Lake Mead area given the similarities in land use and sources of debris input.

We found an average concentration of 0.16 microplastics/g dry weight among all sediment samples (Figure 5). This is similar to findings from Dean et al. (2018), who found between 0.01–0.46 microplastics/g dry weight in sediments among four Lake Erie tributaries.

I hypothesized that Irondequoit Bay and Long Pond would have the highest microplastic concentrations due to being highly residential and popular recreational areas. Additionally, Irondequoit Bay receives WWTP effluent, and Long Pond is located downstream from a closed landfill. This hypothesis was partially supported: Irondequoit Bay had the highest microplastic concentration (6.3 microplastics/m^3) among surface samples, while Long Pond's average concentration was half that (3.8 microplastics/m^3). My hypothesis was further supported among sediment samples: Long Pong had the highest concentration among sediments (0.28 microplastics/g dry weight) followed by Irondequoit Bay (0.16 microplastics/g dry weight). Genesee River had a similar concentration to Irondequoit Bay, with an average of 0.13 microplastics/g dry weight, while Oak Orchard had the lowest sediment concentration with 0.02 microplastics/g dry weight. Irondequoit Bay was the only study site that

received WWTP effluent, which may contribute to higher microplastic concentrations compared to the other sites. An average of 13 billion microplastics are released into US waterways every day from municipal wastewater facilities, or 0.05 microplastics/liter of effluent (Mason et al. 2016). It is more difficult to determine the amount of microplastics that enter waterways due to landfill leachate, as there are five known pathways microplastics can enter aquatic environments from landfills including stormwater or surface runoff, atmospheric transport (due to wind), transference through leachate either by direct discharge or leakage from drainage, microbes and terrestrial organisms present in landfills as carriers, and application of treated leachate as soil conditioner (Upadhyay and Bajpai 2021). However, some estimates exist for landfills in China and Nordic countries. In southern China, an estimated 0.42–24.58 microplastics/L of leachate were found (He et al. 2019) while Nordic countries had a range of 0–4.51 items/L of leachate (Praagh et al. 2018). While these ranges are higher than the average number of microplastics found per liter of WWTP effluent, these estimates are for active landfills. The landfill near the source of Long Pond is no longer active and therefore may not pose as great a risk of contamination as active sites.

Particle morphology distribution

Fibers were the most common particle morphologies in tributary surface samples while fragments were the most common morphology found in lake surface samples (Figure 6), supporting my hypothesis. Overall, fragments comprised the majority of plastic particles recovered from both lake and tributary surface samples.

Mason et al. (2020) also found that fragments were the most common particle type in surface waters of Lake Ontario. Similarly, fragments were the most common morphology found in Lake Huron and Lake Erie (Cable et al. 2017), Lake Michigan (Mason et al. 2016), as well as Lake Hovsgol in Mongolia (Free et al. 2014). The data suggest that the fragments we recovered consist of polymers that are less dense than freshwater and have not been in the environment long enough to develop a biofilm layer heavy enough to promote sinking. This is supported by Daily and Hoffman (2020), who discovered that 60-80% of positively buoyant microplastics (PE and PP) that enter Lake Erie stay at the surface for at least six months based on model simulations.

Secondary microplastics are more commonly found in both open water and tributary systems throughout the Great Lakes compared to primary microplastics (Baldwin et al. 2016), and our findings show a similar trend. The only primary plastic morphology studied was microbeads, which were one of the least common morphologies found in surface samples, along with films and foams (Figure 6). The Erie Canal yielded the highest concentration of microbeads. This was unexpected since the Erie Canal does not receive influx from any known WWTPs, a known source of microbeads. It will be important to study the Erie Canal further downstream to better understand concentrations throughout the canal. Further study is warranted because the canal traverses all of New York State and therefore could serve as an important source and sink of microplastic particles.

Microbeads were one of the least common morphologies found among sediment samples (after foams) and were found only in Irondequoit Bay sediments (Figure 11). No microbeads were discovered in Irondequoit Bay surface samples, suggesting these particles were more likely to sink. Due to the Erie Canal's cement substrate, we were unable to collect sediment samples for comparison. However, the cement substrate may encourage resuspension of particles into the water column versus a softer substrate where particles are more likely to mix with sediment and eventually become submerged.

Fibers and fragments comprised over 90% of particles found in tributary sediment samples (Figure 10). These are the most common morphologies found in Great Lakes tributary sediments, as seen in other studies: fibers and fragments accounted for nearly all microplastics in sediments along the Ontario shoreline of Lake Erie (Dean et al. 2018) and the Canadian shoreline of Lake Ontario (Ballent et al. 2016). Fragments also comprised approximately 70% of microplastics in the sediment of Humber Bay, Lake Ontario, Canada (Corcoran et al. 2015). This is also comparable to what we found in the surface waters of tributaries, where fibers and fragments accounted for 86% of microplastics. Fibers and fragments account for the overwhelming majority of microplastics in surface waters and sediments of the tributaries in this study.

Fibers are one of the most common microparticles in WWTP effluent (Mason et al. 2016) and Irondequoit Bay had the second highest concentration of fibers (Figure 7), though this was not significantly different from fiber concentrations at the

other sites. Oak Orchard Creek had the highest microfiber content among all sites, although this was skewed by an outlier surface sample from August 2018 that yielded distinctly more fibers compared to other samples from Oak Orchard Creek (Figure 7). In contrast, Oak Orchard Creek had the lowest fiber content among sediments when compared to the other sites (Figure 11), and fibers were the only microplastic morphology found in Oak Orchard Creek sediments. Fibers may have recently entered the system and not yet developed a biofilm to promote sinking or are staying suspended due to flow. This is likely true for fragments as well, which was the second most common morphology found in Oak Orchard Creek surface samples (Figure 6), as fragments were not discovered in Oak Orchard Creek sediments. This contrasts findings from the other tributaries: fragments and films were found at each site, besides Oak Orchard Creek, in sediments (Figure 11).

Irondequoit Bay and Long Pond surface and sediment samples had similar particle morphology distributions (Figures 6 and 10). Both sites showed higher percentages of fragments in sediments compared to surface waters, along with lower concentrations of foams and beads in sediments. Fiber concentrations were higher in surface waters for both samples, suggesting that fibers are less likely to settle out in substrate at these sites. Fragments, however, are more likely to sink and remain in the sediment. Overall, the predominant microplastic morphology at the surface was also the predominant morphology in the sediment for each site.

Films and foams were the among the least common particle types in both lake and tributary surface samples, which is reflected in other studies in the Great Lakes

(Eriksen et al. 2013, Mason et al. 2020, Mason et al. 2016). All morphologies were found in lake sites though some tributaries did not have films or beads. Since lakes serve as end points for tributaries and have longer shorelines compared to individual tributaries, lakes are more likely to receive a diverse array of plastic debris. Lakes also receive input from other sources. The current closest to the Rochester area runs west to east year-round, bringing debris from Lake Erie and the upper Great Lakes through Niagara Falls. Approximately 9% of microplastics from Lake Erie are transported to Lake Ontario (Hoffman and Hittinger 2017). In addition, microplastics released from the Toronto and Buffalos area are eventually transported to the southern shore of Lake Ontario (Hoffman and Hittinger, 2017), culminating with particles released from Rochester.

Understanding microplastic morphology distribution may help predict effects on wildlife and even humans. Microplastics have been found in many commercial fish species, most of which were fibers (Rochman et al., 2015). Fibers were also the most common microplastic found in Lake Mead fishes and bivalves, comprising 90% of particles found in the gastrointestinal tracts (Baldwin et al., 2020). A myriad of invertebrates, including micro- and mesozooplankton, and benthic deposit feeders, scavengers, and suspension feeders, ingest microplastics, some with a preference for fibers (Wright et al. 2013). Fibers may be commonly found in the digestion systems of wildlife because they are harder for organisms to pass, as they are more likely to become entangled in the gut compared to other morphologies. Research on the effects of ingestion on wildlife and human health are varied and inconclusive but may pose

health risks at certain contamination levels. There is some evidence that microplastics and their contaminants may be transferred from lower to higher trophic levels (Wright et al. 2013). Eight species of fish from nearshore Lake Ontario from varying trophic levels are known to ingest microplastics, with up to 915 microplastics in a single fish (Munno et al. 2021). Microplastic abundance in the gastrointestinal tract of Great Lakes fishes increased with fish length, indicating microplastics can impact larger species and potentially higher trophic levels.

Polymer distribution

I hypothesized that polyethylene (PE) and polypropylene (PP) would be the most common polymers at surface level among all sites. This was partially supported: PE and Other were the most common categories (Figure 13), accounting for 90% of the particles analyzed in both surface and sediment samples. PE was discovered in all surface sites except the Erie Canal and Oak Orchard; Other polymers were found in all surface sites except Irondequoit Bay and Oak Orchard (Figure 15). PE is the most common polymer in production today and accounts for 34% of the total plastics market (Plastics Europe 2015). It is widely used in food packaging, water bottles, toys, milk bottles, shampoo bottles, pipes, and other houseware items. Its ubiquity in global plastic production and in everyday items make it more likely to end up in the environment.

I expected to find more PP, which accounted for less than 10% of polymers analyzed, not supporting my hypothesis. PP was the second most common polymer found in Lake Erie and Lake Ontario (Mason et al. 2020) and Lake Michigan (Mason

et al. 2016). Some of this difference may be attributed to different polymer concentrations in lakes versus tributaries. We found PP in lake samples, though in lower concentrations compared to previous studies, but none in tributary samples. Our findings may also differ because of different instrumentation (FTIR vs Raman microscopy) and databases used to identify polymers. In this study, a threshold of 85% was used to classify polymers, whereas previous studies do not identify a threshold, possibly leading to different categorization.

Polyethylene's (PE) prevalence in local waterways may have implications on wildlife and ambient water. Rochman et al. (2012) found that polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) sorbed to PE at significantly greater concentrations when compared to other plastic polymers, making these polymers a greater risk for contaminating wildlife if ingested. PCBs bioaccumulate up the food chain, resulting in higher concentrations and toxicity in higher trophic levels. Exposure to PCBs can disrupt fish thyroid functioning and steroid hormone systems (Simmons et al., 2014). While PCB concentrations have been decreasing throughout the Great Lakes, Lake Ontario has the most severe PCB concentrations in fish, including the Rochester-area basin (Visha et al. 2018). PE may be an important transporter of PAHs and PCBs to both wildlife and humans.

Consumption of contaminated fish and invertebrates can transport these chemical compounds to humans as well, with potential impacts on human health. PAHs and PCBs are linked to both short-term and long-term human health effects. Humans currently ingest or inhale 883 particles/capita/day, the equivalent of 583

nanograms/capita/day (Nor et al. 2021). Drinking water is also known to carry plastics: microplastics, mostly fibers, have been found in tap water from 14 countries, with the highest concentrations found in the United States (Kosuth et al. 2018). Nor et al. (2021) also discovered that PCB126, a known carcinogen, increased in human adipose tissues after ingesting microplastics. PAHs and PCBs may be transported to human tissues as well, particularly through PE. However, more research is needed to understand the long-term effects of plastic ingestion on human health.

The surface particles I analyzed from Oak Orchard were not plastic and accounted for the majority of non-plastic particles that I analyzed (Figure 15). Only 8% of surface particles, and less than 5% of sediment particles, were classified as non-plastic, suggesting most particles were accurately identified as plastic. Most particles classified as non-plastic (63%) had a plastic component but did not meet the 85% threshold used to positively identify plastic polymers. I would like to reanalyze these particles with a lower threshold to learn if they are predominantly plastic or are primarily composed of other materials. Only PE (5%), Other (91%), and non-plastics (4%) were found in sediment samples (Figure 17). The most common polymers included in Other were copolyamide, an adhesive used in textiles, adhesives, and construction, and polyvinyl acetate, found in many types of glue. Nylon, ethylene acetate, nitrile, and epoxy were also found and categorized as Other. I expected to find all polymer categories in sediment samples, either due to high-density polymers such as PVC and PS, or an accumulated biofilm. In comparison, Ballent et al. (2016) found fourteen polymer types in sediments of 66 watersheds in the Lake Ontario

basin, 31% of which were PE. Current models predict that at least half of microplastics are deposited in the benthos of Lake Erie, with an increase in the amount of particles deposited over time (Daily and Hoffman 2020). Microplastics in tributaries may remain at the surface longer due to flow and turbulence, especially during spring and summer months when melting and storm events increase the rate of flow. Particles are more likely to enter tributaries during warmer months when the water is not frozen, and therefore are more likely to enter the system when water is more turbulent. This may prevent particles from becoming deposited, and instead transported to the lake. Further research could focus on sampling sediments at tributary deltas and nearshore lake sites for comparison.

Conclusions and Future Research

While research is evolving on microplastic pollution in the Great Lakes, many questions remain. Understanding major sources of plastic debris and how they enter the Great Lakes is vital to creating solutions. This study provides the first comparison of surface-level microplastic concentrations in nearshore Lake Ontario versus its tributaries, as well as concentrations of microplastics in the Rochester embayment. This study also provides a survey of microplastic concentrations in sediment versus surface waters within Rochester-area tributaries, including an analysis of polymer types, offering an assessment of microplastic trends in a locale not previously studied. Future research focused on microplastic concentrations in nearshore sediment of the southern Lake Ontario shoreline, concentrations and transport of microplastics from local WWTPs, transport of debris from Lake Erie and the upper Great Lakes, and

assessment of shoreline plastic debris will be essential to understanding the fate of microplastics in the Lake Ontario basin. It will also be important to continue comparing field data to current models, such as those created by Hoffman and Hittinger (2017), Daily and Hoffman (2020), and Cable et al. (2017), to better predict sinks and sources of plastic debris in the Great Lakes. Continuing to learn the distribution and transport of plastic morphologies and polymers can contribute to finding sources of pollution, and more importantly, help to create targeted pollution prevention strategies.

It would be interesting to resample the study sites to compare the concentrations and types of polymers before and after the COVID outbreak, when there was an exponential increase in the use of single-use masks, gloves, and sanitary wipes. An estimated 1.56 billion masks entered the oceans in 2020 alone (Phelps Bondaroff and Cooke 2020), and the Great Lakes basin has likely been affected by the increase in single-use personal protective equipment as well.

Plastic pollution is a complex environmental issue that will require a multifaceted approach to building solutions. As the field of microplastic research grows, it will be important to engage nonprofits, governmental organizations, the private sector, and the public in creating solutions, particularly those targeted at prevention strategies. Many solutions exist but need to be implemented through the collaboration of science, policymaking, and community outreach. For example, treating primary WWTP effluent with membrane bioreactors can eliminate up to 99.9% of microplastics from effluent before it is released into local waterways

(Talvitie et al. 2017). More than 50 technologies have been developed that either prevent plastic from entering waterways, such as stormwater and wastewater filters, or collect existing plastic pollution from aquatic environments, including large-scale booms, drones, and robots (Schmaltz et al. 2020). Understanding trends in local and regional plastic debris can aid decision-makers in implementing strategies to prevent and remove plastic pollution from our waterways that are fit-for-purpose and relevant to the local ecosystem, thereby providing a safer, cleaner environment for humans and wildlife.

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TABLES AND FIGURES

Table 1. The number of surface samples processed from each study site. Tributary samples were taken once monthly from August to September 2018 and June to August 2019 and from June to August 2019 for lake sites. The Genesee River was inaccessible throughout 2019 due to flooding, resulting in only one sample collected. One Oak Orchard Creek sample broke during transit.

Site	**n (surface samples)**	**n (sediment samples)**
Oak Orchard	4	2
Long Pond	5	3
Irondequoit Bay	4	3
Genesee River	1	2
Erie Canal	4	N/a
LO East	3	N/a
LO Center	3	N/a
LO West	3	N/a
Total	27	10

Table 2. Plastic polymers were categorized based on the most common polymers in production worldwide as well as the recycling number system for plastics in the United States.

Polymer	**Percent of plastic produced globally**	**Recycling number (USA)**
Polyethylene Terephthalate (PET)	7%	1
Polyethylene (PE)	34%	2 (High-density PE) and 4 (Low-density PE)
Polyvinyl Chloride (PVC)	11%	3
Polypropylene (PP)	19%	5
Polystyrene (PS)	7%	6
Polycarbonate, BPA, and Other Plastics	22%	7

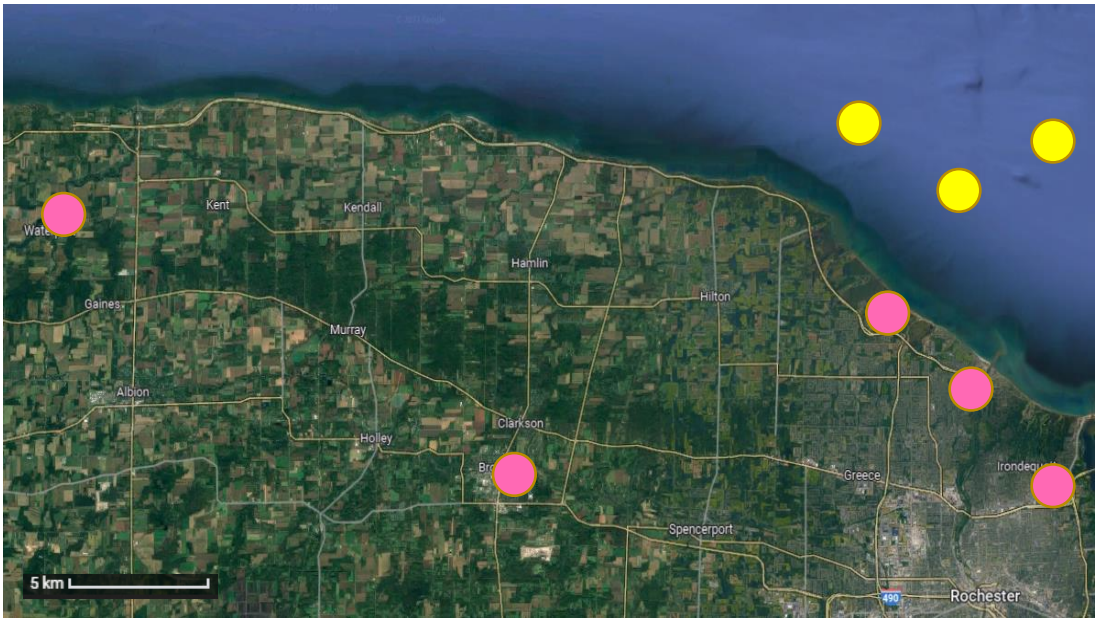


Figure 1. Map of study sites including tributaries (pink) and lake sites (yellow) in Orleans and Monroe Counties, New York. Tributary sites from left to right are Oak Orchard Creek, Erie Canal, Long Pond, Genesee River, and Irondequoit Bay. Lake sites from left to right are Lake Ontario East, Lake Ontario Center, and Lake Ontario West. Lake sites were approximately four km apart.

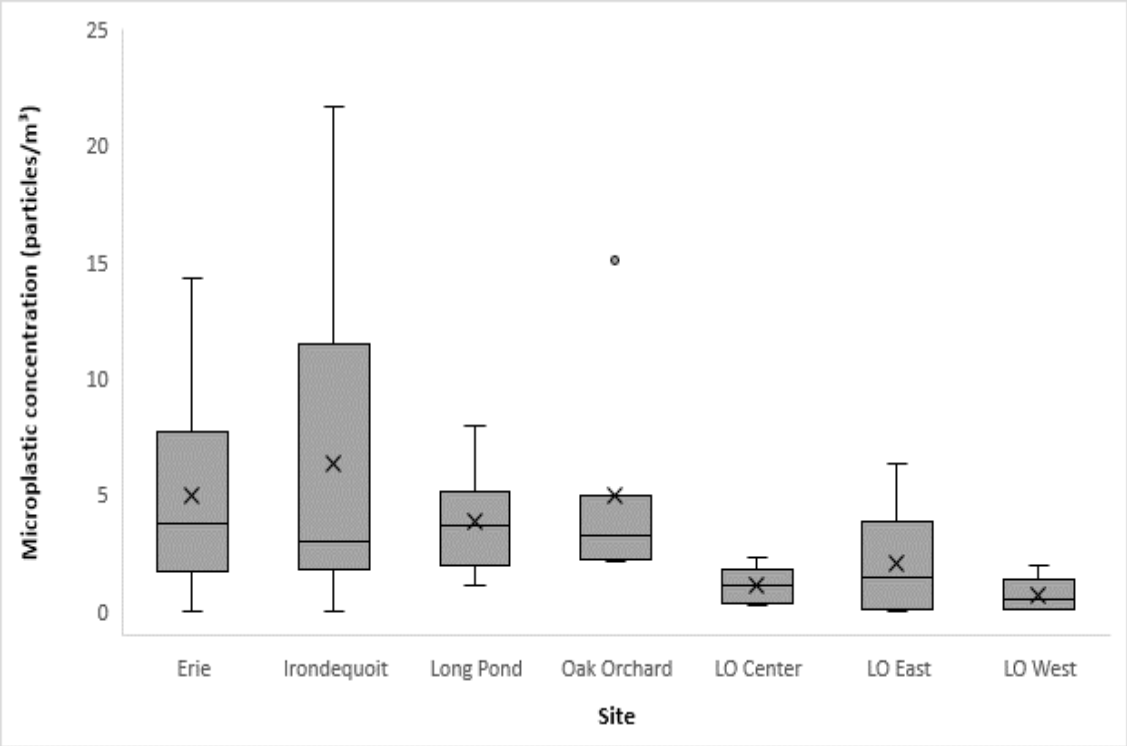


Figure 2. Distribution of microplastic concentrations among tributary and lake surface samples. Bars represent the minimum to maximum concentrations (range), the ends of the box represent the first and third quartiles, the line in the box represents the median concentration, and the x in the box represents the mean concentration. The point in Oak Orchard Creek represents an outlier. Average tributary concentrations equaled 4.9 microplastics/m³ versus the average lake concentration of 1.3 microplastics/m³. Irondequoit Bay had the highest overall concentrations. Genesee River was not included in this analysis due to small sample size (n=1).

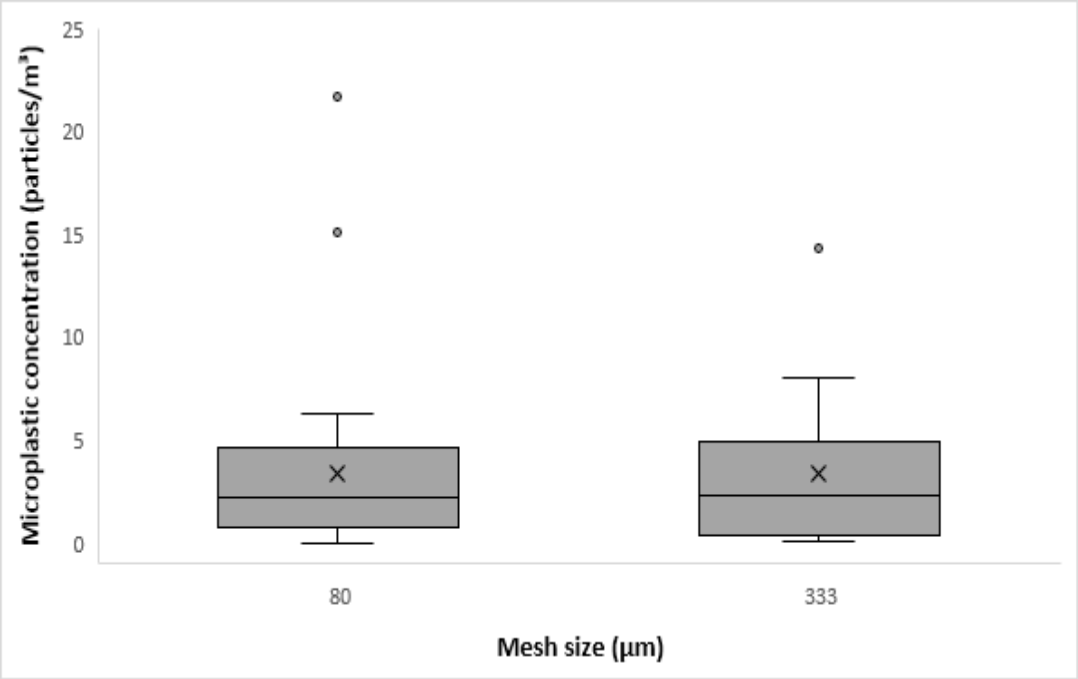
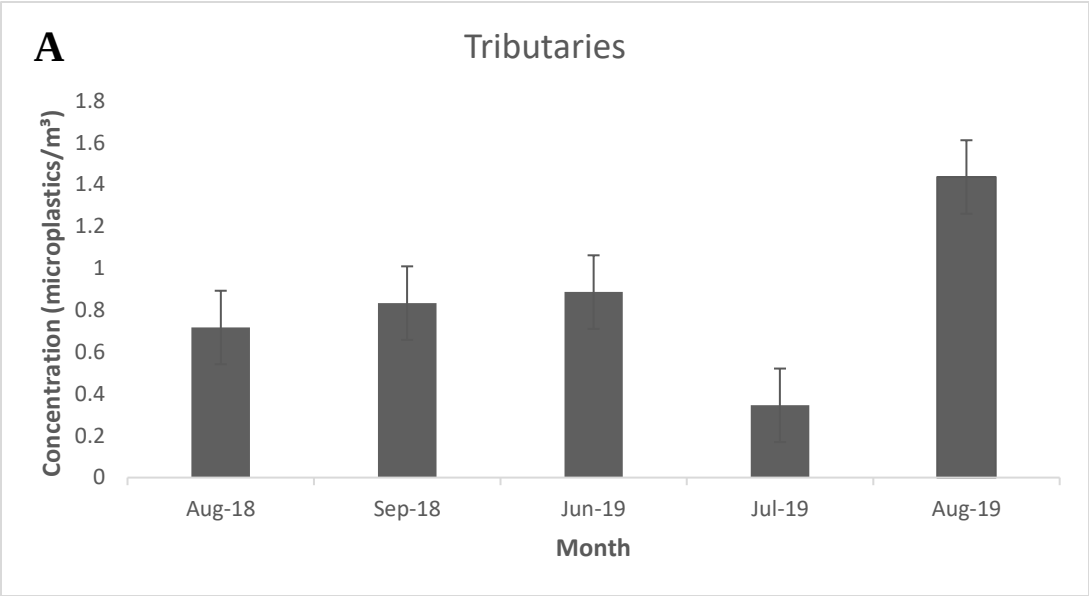


Figure 3. The 80 µm net captured an average of 2.8 microplastics/m³, slightly lower than an average 3.5 of microplastics/m³ captured in the 333 µm net, though this was not statistically significant (paired two sample t-test, p=0.57, df = 18, t Critical two-tail = 2.1)



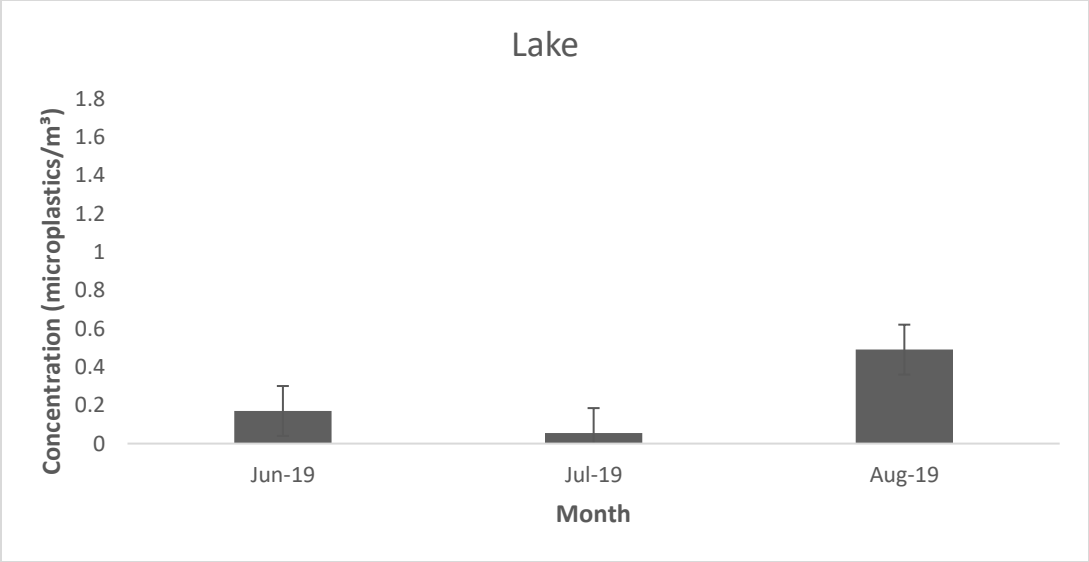


Figure 4. Changes in microplastic concentration over time for tributaries (A) and lake sites (B) using the 333 µm net. Both systems showed a decrease in microplastics in July 2019 followed by an increase in August. Tributary sites showed higher overall concentrations in 2019 compared to 2018. N = 18 for tributaries, n = 9 for lake sites.

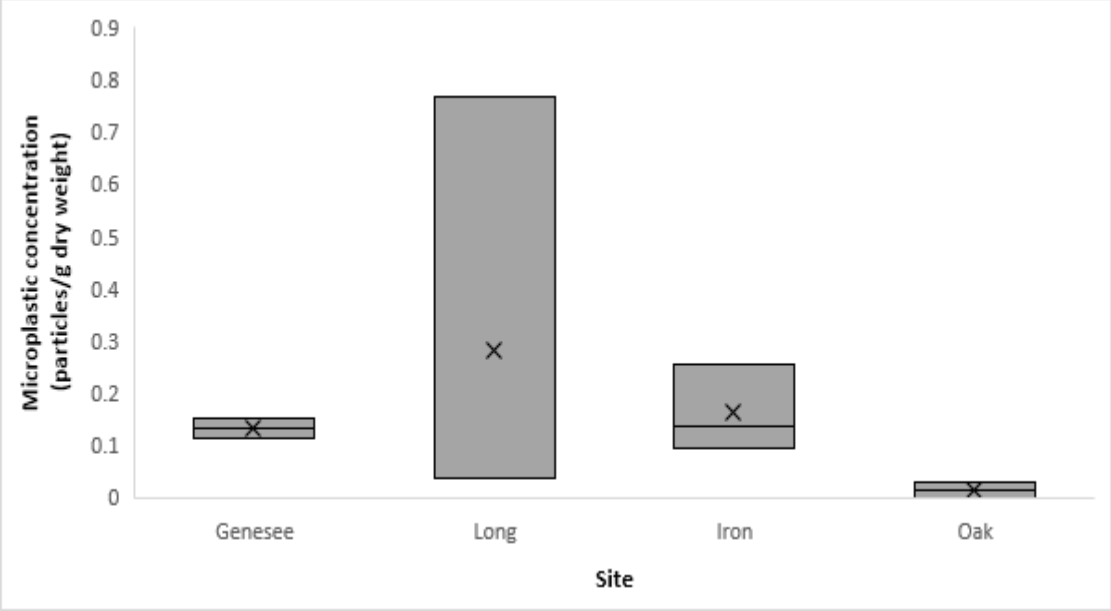


Figure 5. Distribution of microplastic concentrations in tributary sediments. The ends of each box represent the first and third quartiles, the line in the box represents the median concentration, and the x in the box represents the mean concentration. Long Pond had the highest concentration (average = 0.28 microplastics/g dry weight) while Oak Orchard Creek had the lowest (average = 0.02 microplastics/g dry weight).

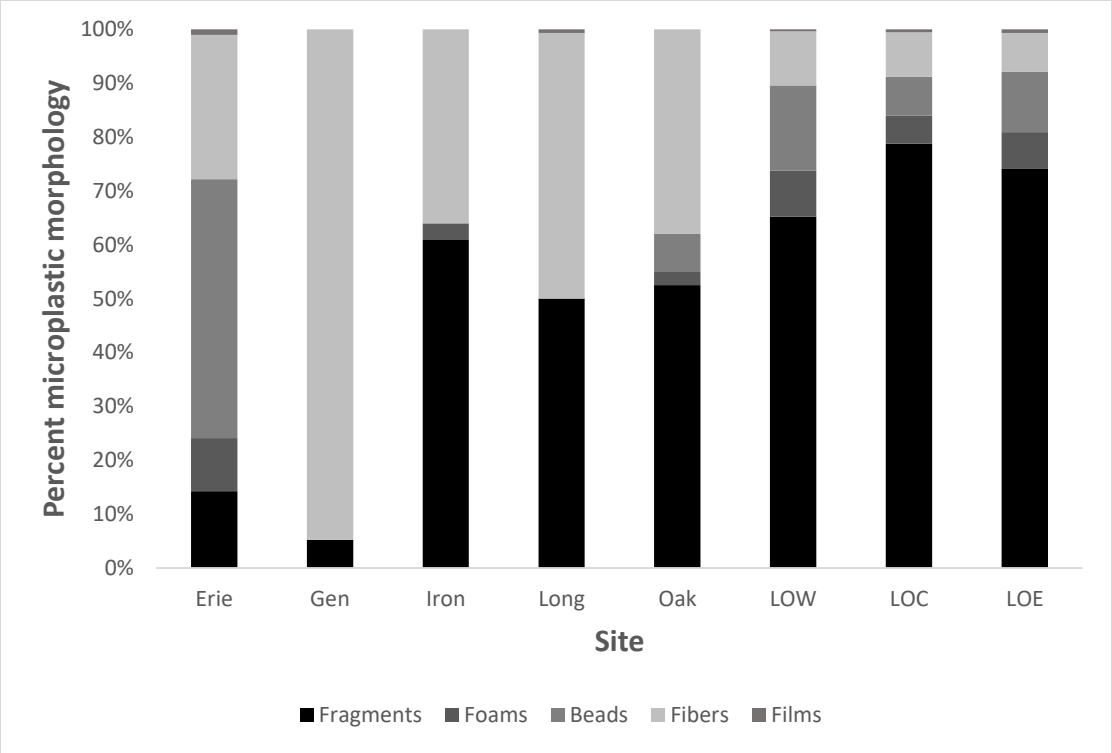


Figure 6. Percentage of plastic morphology by site for surface samples collected with the 333 µm net. Fragments and fibers were the most common morphologies found among sites. Lake sites contained the highest proportion of fragments, while tributaries contained similar proportions of both fragments and fibers. N = 4 for Erie Canal, n = 1 for Genesee River, n = 4 for Irondequoit, n = 5 for Long Pond, n = 4 for Oak Orchard, n = 3 for each lake site.

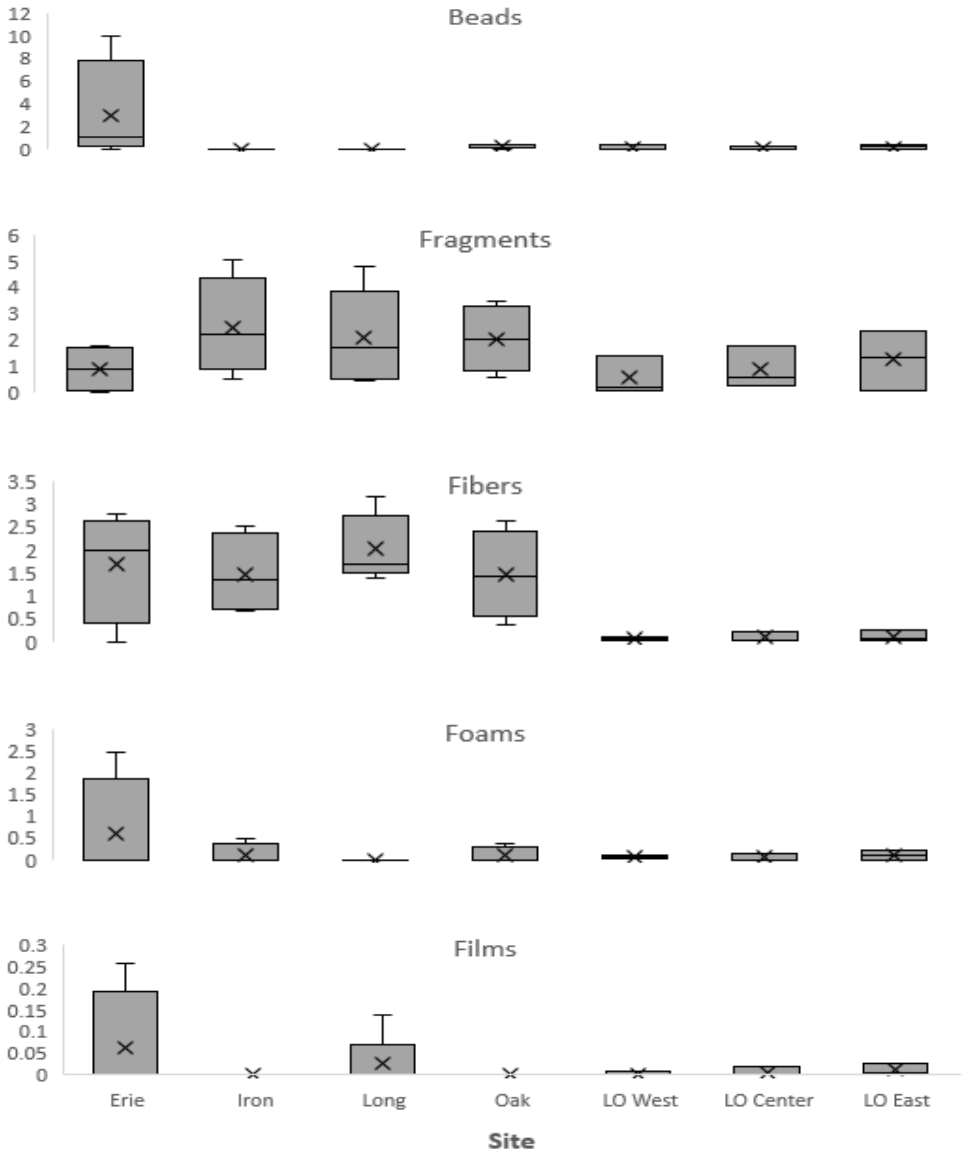


Figure 7. Distribution of microplastic morphologies among surface samples where bars represent the range, the ends of the box represent the first and third quartiles, the line in the box represents the median, and x represents the mean. Beads and fibers showed a significant difference in concentration among sites though post-hoc tests did not show significantly different concentrations. Genesee River was not included in this analysis due to small sample size (n=1).

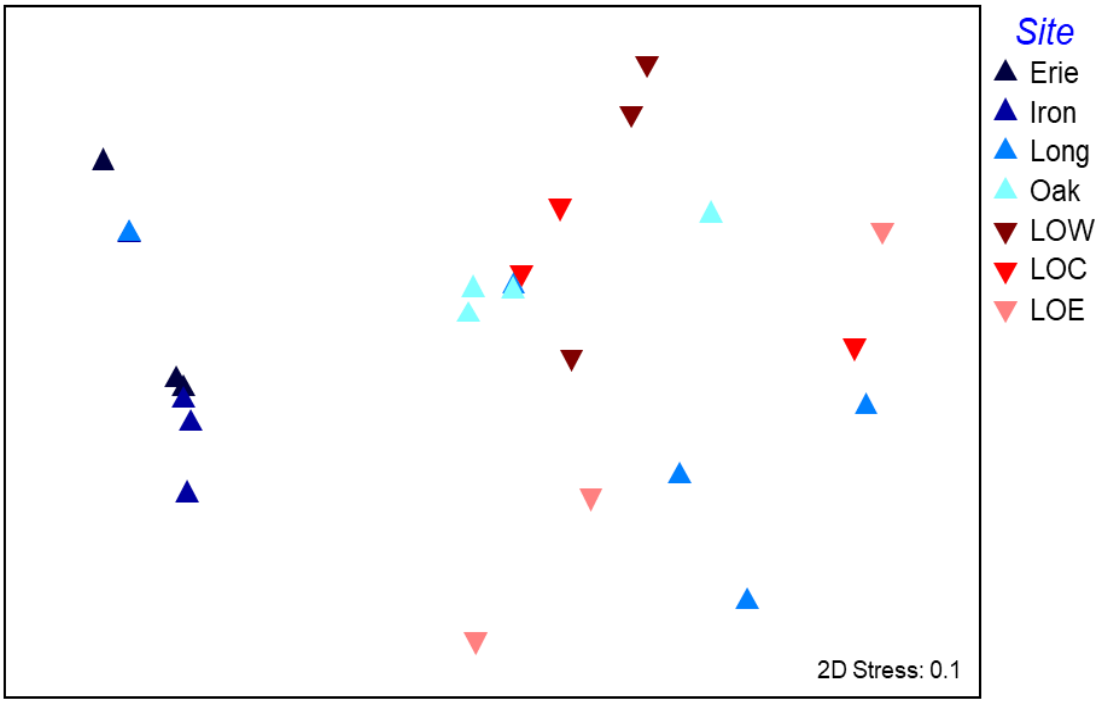


Figure 8. NMDS plot showing dissimilarity of morphology concentration among all surface samples. Morphology concentrations among lake sites (red) were more similar to each other than tributary sites (blue), which showed more variation in their concentrations. Erie Canal and Irondequoit Bay were more similar in their concentrations compared to Long Pond and Oak Orchard, which had concentrations more similar to lake sites. Stress = 0.1.

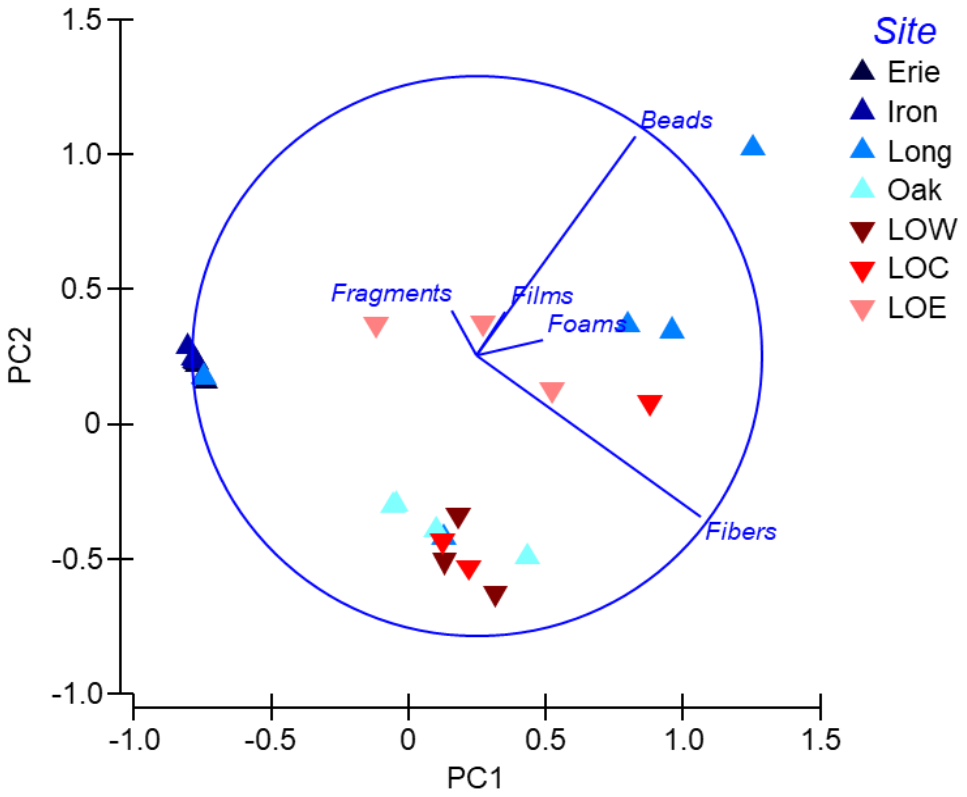


Figure 9. Principal Component Analysis (PCA) showing relationship between morphology type and site. Tributaries (blue) showed stronger relationships with fibers and fragments compared to lake sites (red). Fibers and beads had strong relationships with site (Eigenvector = 0.79 and 0.78, respectively). Fragments, foams and films showed very weak relationships by site (Eigenvector = 0.16, 0.24 and 0.16, respectively).

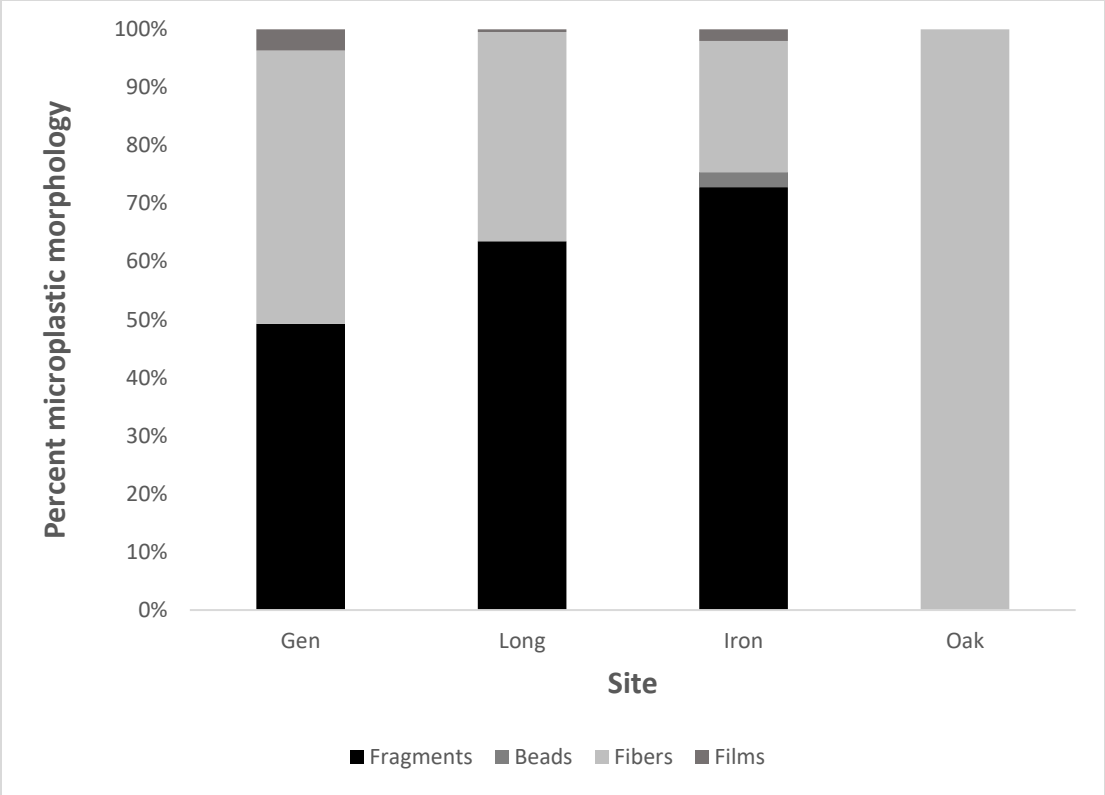


Figure 10. Percentage of plastic morphology by site for sediment samples. Fragments and fibers were the most common morphologies found among sites. Fibers were the only type found in Oak Orchard Creek. N = 3 for Irondequoit Bay and Long Pond, n = 2 for Genesee River and Oak Orchard.

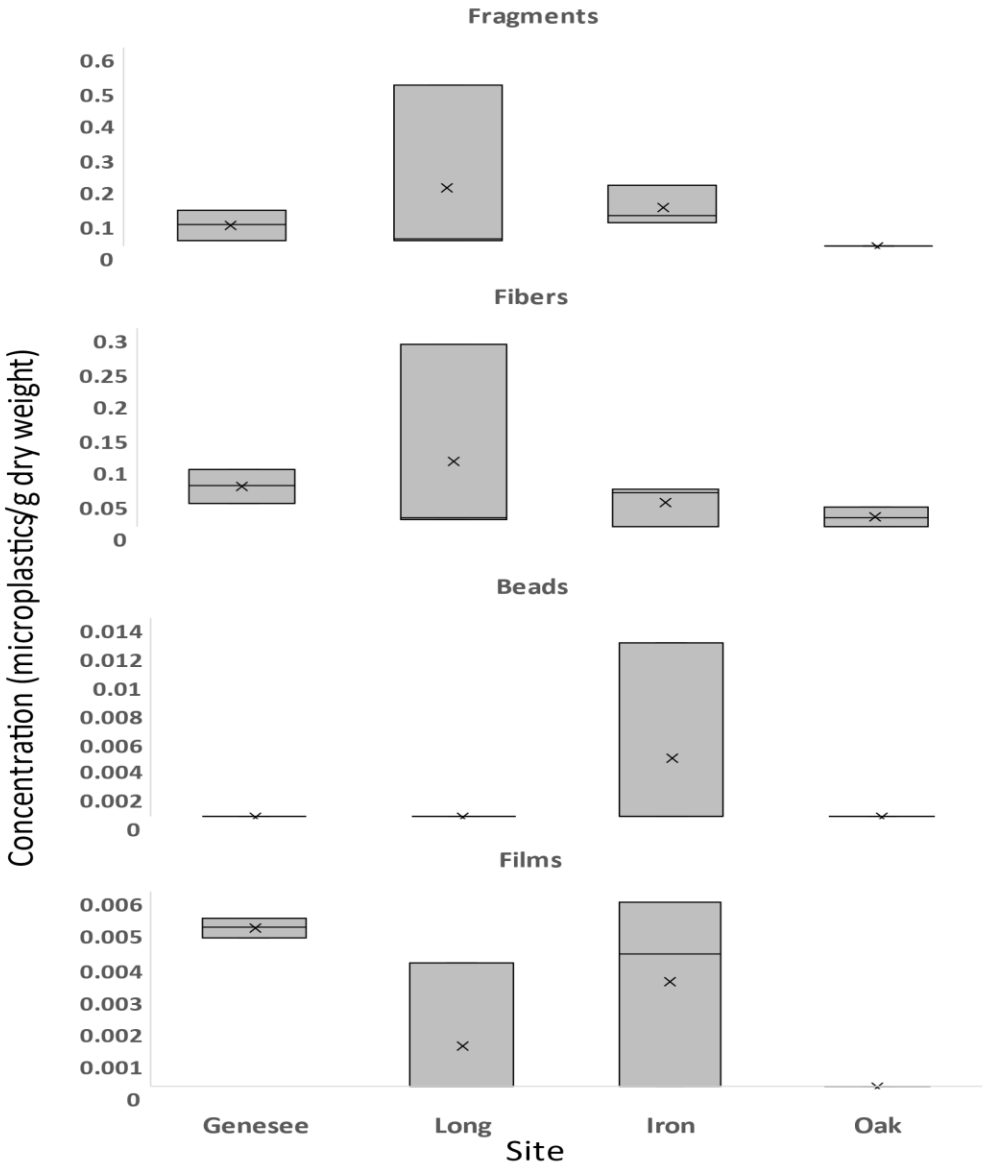


Figure 11. Distribution of fragments, fibers, films, and beads among tributary sediments where the ends of the box represent the first and third quartiles, the line in the box represents the median, and x represents the mean. Fibers were the only particle type found in Oak Orchard. Irondequoit Bay was the only site that contained microbeads. Fragments and fibers were the most common morphologies among all sites.

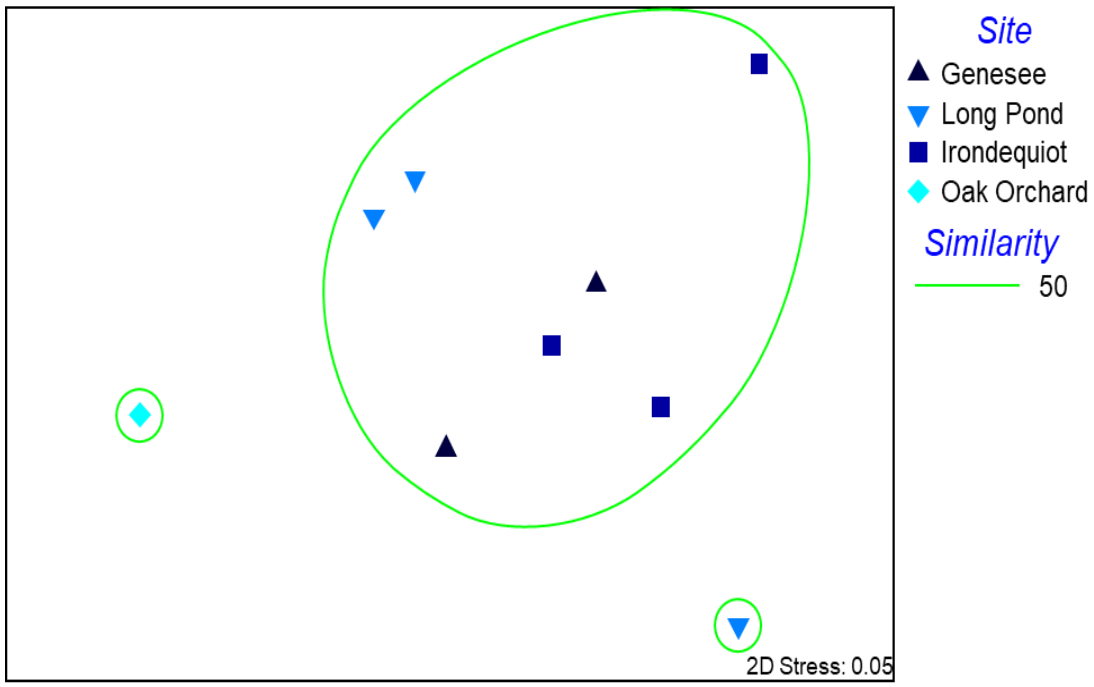


Figure 12. NMDS plot of morphology concentrations among sediments. There are no clear patterns among sites. Two samples, Oak Orchard from June 2019 and Long Pond from June 2019, were especially dissimilar from the others. Foams were not found in any sediment samples and is therefore not included. The two samples from Oak Orchard are overlapping, indicating strong similarity in morphological concentration within the site. Stress = 0.05.

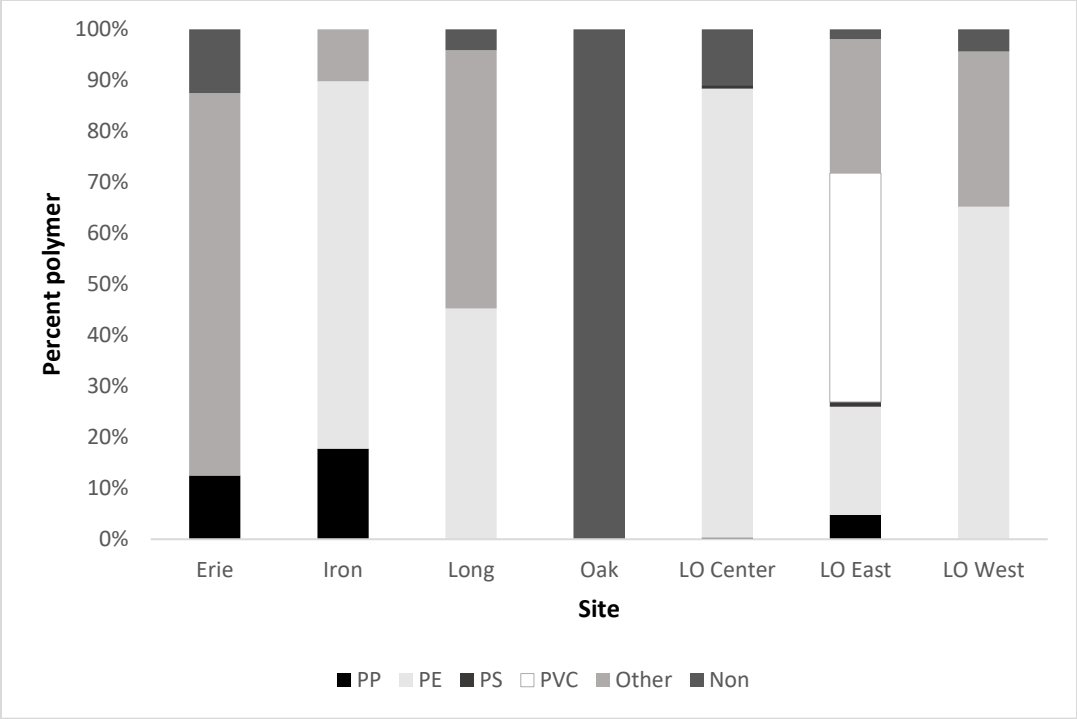


Figure 13. Percent of polymer type among surface samples collected with 333 µm net. The most common morphologies were other and polyethylene (PE). Samples analyzed from Oak Orchard Creek were not identified as plastic. N = 4 for Erie Canal, Irondequoit Bay and Oak Orchard, n = 5 for Long Pond.

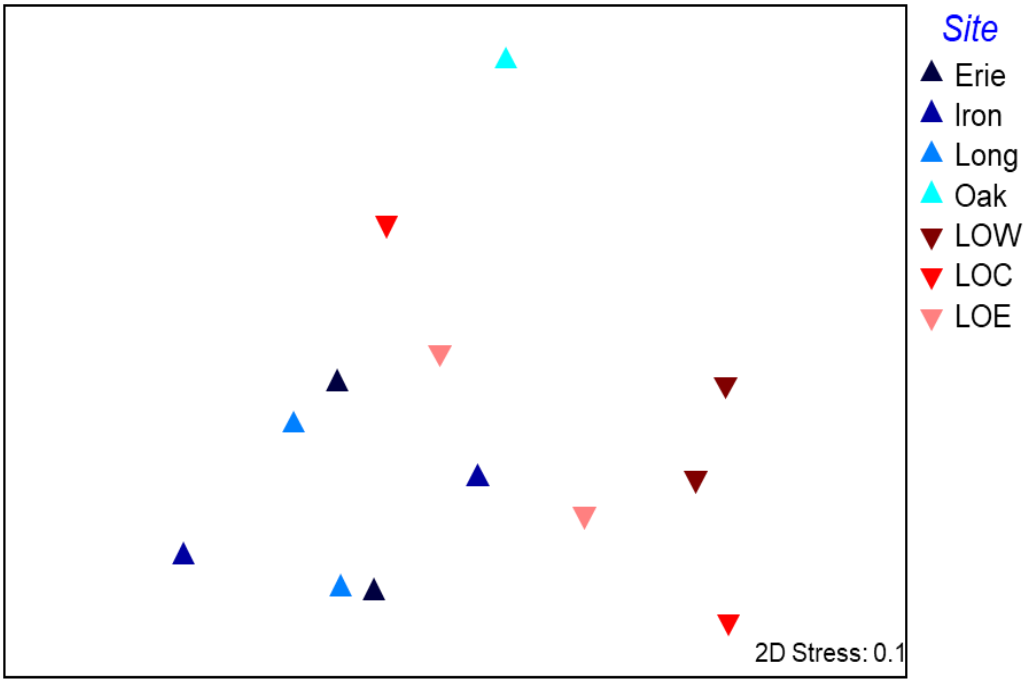


Figure 14. NMDS plot of polymer concentrations among surface samples. Lake sites (red) and tributary sites (blue) show separate clusters, indicating similar polymer concentrations within tributary sites and within lake sites. N = 2 for all sites. Oak Orchard is overlapping, indicating polymer concentration was very similar in both samples. Stress = 0.10.

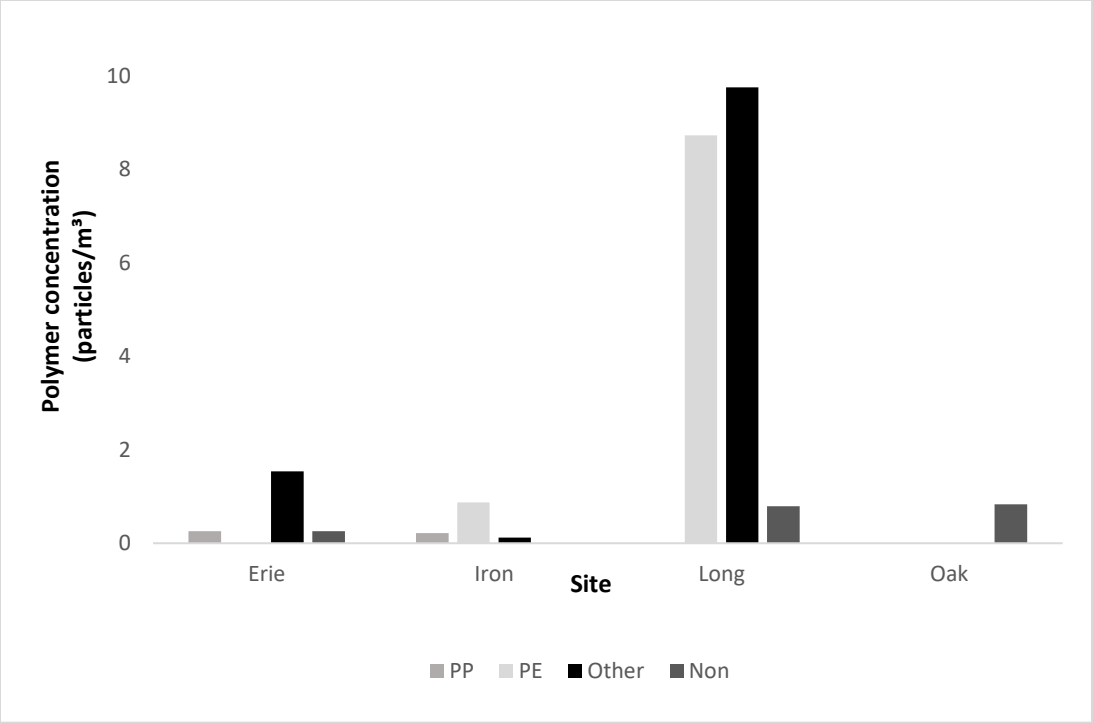


Figure 15. Polymers found in surface samples among tributaries. Long Pond had the highest concentration of polyethylene and other polymers. Polystyrene, polyvinyl chloride, and polyethylene terephthalate were not found in tributary surfaces. Oak Orchard Creek only had non-plastic because the particles analyzed contained a plastic polymer but did not meet the threshold of 85% matching in the plastic identification database. N = 2 for each site.

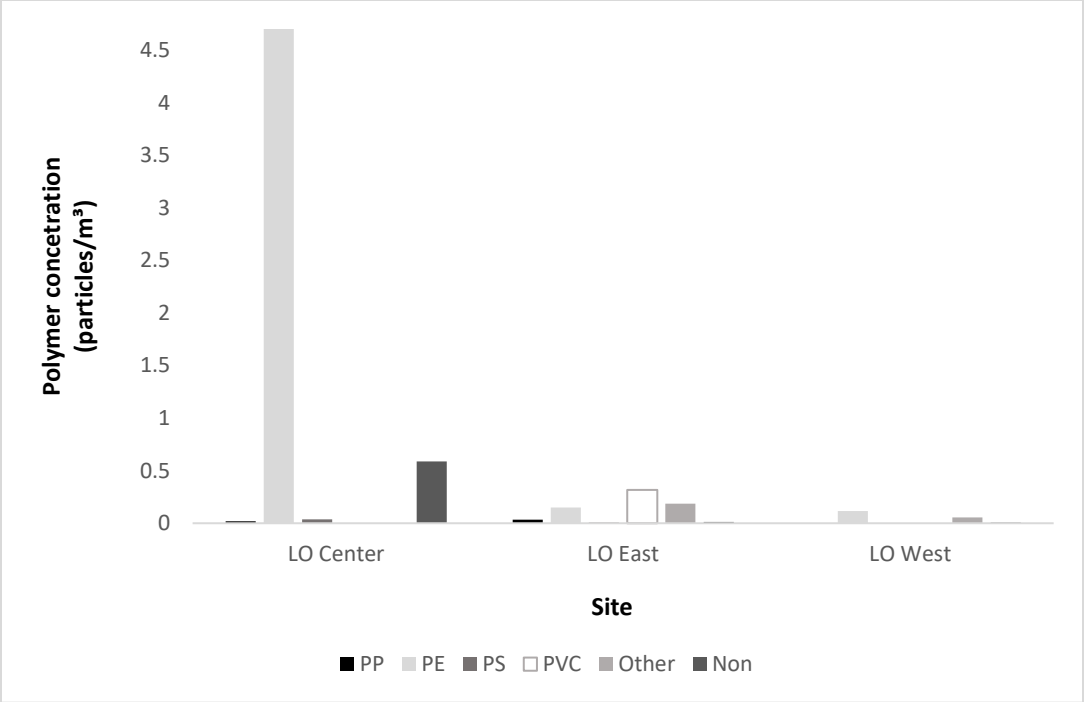


Figure 16. Polymers found in surface lake samples showed Lake Ontario Center had the highest concentration of polyethylene. N = 2 for each site.

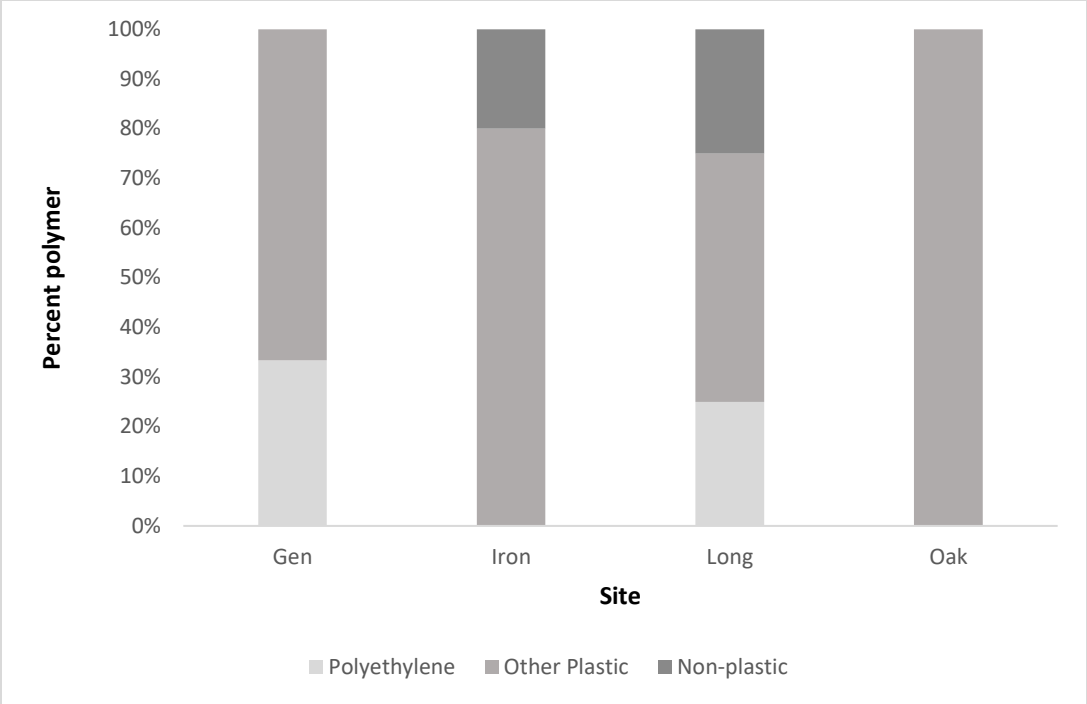


Figure 17. Percent of polymer type among sediment samples. The most common morphology was Other (91%). Less than 5% of particles were not plastic. Polypropylene, polystyrene, polyvinyl chloride, and polyethylene terephthalate were not found in sediments. N = 3 for Irondequoit Bay and Long Pond, n = 2 for Genesee River and Oak Orchard Creek.