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Factors influencing microplastic abundances in nearshore, tributary and beach sediments along the Ontario shoreline of Lake Erie

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ABSTRACT

Sediment samples were collected from nearshore, tributary and beach environments within and surrounding the northern part of Lake Erie, Ontario to determine the concentrations and distribution of microplastics. Following density separation and microscopic analysis of 29 samples, a total of 1178 microplastic particles were identified. Thirteen nearshore samples contained 0–391 microplastic particles per kg dry weight sediment (kg^{-1}), whereas 4 tributary samples contained 10–462 kg^{-1} and 12 beach samples contained 50–146 kg^{-1}. The highest concentrations of nearshore microplastics were from near the mouths of the Detroit River in the western basin and the Grand River in the eastern basin, reflecting an urban influence. The highest microplastic concentrations in beach samples were determined from Rondeau Beach in the central basin where geomorphology affects plastics concentration. The Welland Canal sample in the eastern basin contained the greatest concentration of microplastics of the tributary samples, which is consistent with high population density and shipping traffic. The overall abundance of microplastic in northern Lake Erie nearshore, tributary and beach samples is 6 times lower than in sediment sampled from northern Lake Ontario. The nearshore and beach sample results potentially reflect the transport patterns of floating plastics modeled for Lake Erie, which predict that the majority of plastic particles entering the lake are transported to southern shoreline regions rather than northern areas.

Introduction

Rivers, lakes, seas and oceans are polluted with plastics globally, as waste is either transferred from urban centers through natural and anthropogenic watercourses or is deposited directly from marine vessels. Plastic debris in aquatic environments has been shown to cause detrimental effects on various organisms (Gall and Thompson, 2015; Gregory, 2009; Kühn et al., 2015; Laist, 1997). These effects include entanglement in nets, ropes, packing loops, monofilament lines and other items (e.g. Innis et al., 2010; McIntosh et al., 2015; Yorio et al., 2014), ingestion by organisms such as birds, fish, and invertebrates (e.g. Pham et al., 2017; Possatto et al., 2011; Provencher et al., 2014), potential transfer of adsorbed pollutants from the surfaces of plastics to organisms (e.g. Colabuono et al., 2010; Endo et al., 2005; Koelmans et al., 2014), and encrustation of plastic objects leading to the transport of invasive species (Gregory, 2009; Tutman et al., 2017). Determining the inventory of plastic particles in benthic sediment enables identification of areas of increased risk for bottom-dwelling and -feeding organisms. Microplastic particles have been shown to adsorb pollutants, thereby exposing benthic invertebrates to chemicals during ingestion and possibly transferring them through the food web (van Cauwenberghe et al., 2015). Although investigations concerning plastic debris in surface water, shoreline, and land-based environments are extensive, comparably less information is available concerning benthic plastic debris, especially in lake basins. Buried plastic is not exposed to major degrading agents like UVB radiation and mechanical abrasion; and therefore, the negative effects of plastics may persist for 100s to 1000s of years (Barnes et al., 2009).

Microplastics have been reported from lake systems in many countries including, but not limited to Canada (e.g. Anderson et al., 2017; Ballent et al., 2016), China (e.g. Su et al., 2016; Zhang et al., 2016), India (e.g. Sruthy and Ramasamy, 2017), Italy (e.g. Sighicelli et al., 2018), Kenya/Uganda/Tanzania (Lake Victoria) (e.g. Khan et al., 2018), Switzerland (e.g. Faure et al., 2015), the UK (e.g. Vaughan et al., 2017), and the USA (e.g. Lasee et al., 2017). The only known published studies concerning benthic plastic debris in the Laurentian Great Lakes system were conducted in the St. Lawrence River (Castañeda et al., 2014) and Lake Ontario (Ballent et al., 2016; Corcoran et al., 2015). The main objective of this paper is to present the distribution and abundance of microplastics in benthic sediments of Lake Erie, and its tributaries. The results are compared with microplastic abundances on Lake Erie beaches, and with distribution models depicting the transport and depositional location of plastic debris throughout the lake. The work

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focuses on microplastics, which are defined as plastic particles <5 mm in size. Microplastics are derived from degradation of larger plastic products, or are manufactured as mm-size particles, such as pellets and microbeads.

Methods

Study area

Lake Erie is approximately 388 km long, has an average depth of 19 m, and has a breadth of 92 km (EPA, 2015). Water flows into Lake Erie through the Detroit River, which drains Lake St. Clair. There are three basins comprising Lake Erie; the western, eastern and central basins (Fig. 1). The amount of plastic debris surrounding and in Lake Erie could be influenced by: 1) its location downstream from Lakes Superior, Michigan, Huron, and St. Clair, 2) surface water circulation patterns, 3) sedimentation rates, 4) population density (a surrogate for plastics use), and 5) proximity to plastics use and manufacturing industries. Lake Erie is characterized by a two-gyre water circulation pattern (Fig. 1a, b). High winds during the winter season result in a strong circulation with anticyclonic movement in the northern part and cyclonic movement in the southern part of the lake. During the summer season, the dominant gyre is anticyclonic, with a minor cyclonic gyre in the western part of the lake (Beletsky et al., 1999). The complicated annual circulation patterns possibly contribute to varying sedimentation rates in the lake. Kemp et al. (1974) reported mean annual sediment accumulation of 1.1 to 13.4 mm/yr, with the greatest accumulation in the eastern basin. Similarly, Robbins et al. (1978) determined average annual sediment accumulation values of 10 mm/yr in eastern Lake Erie.

Approximately 12 million people live in the Lake Erie watershed, which represents one third of the population in the Great Lakes region (EPA, 2017). The quaternary watersheds closest to Lake Erie in Ontario, Canada are highly populated within 25–75 km of the lake. In addition to water circulation patterns, sedimentation rates, and population density, plastics accumulation may also be influenced by industries. Of the 50 U.S. states that have plastic industries, Ohio is ranked 3rd (The Plastics Industry Trade Association, 2015), and approximately 47% of the Canadian plastics industry is located in Ontario (Government of Canada, 2017). Plastic pellets from production plants are prone to spillage within factories as well as during transportation or off-loading, which can result in pellets moving down storm drains into rivers and lakes during rain events (Corcoran et al., 2015; Zbyszewski et al., 2014).

Sample collection and processing

Thirteen benthic sediment samples were collected in August 2014 by the Ontario Ministry of Environment and Climate Change (MOECC) using a Shipek sediment grab sampler (Wildco, Yulee, FL, USA). Ten samples were collected from Lake Erie nearshore locations, 1 from the mouth of the Grand River and 1 from the Detroit River (Fig. 2). At each station, the top 3 cm of three discrete grabs were homogenized in pre-cleaned stainless steel pans and transferred to a 500 mL polyethylene terephthalate (PET) jar. The samples were chilled and transported to the laboratory for analysis. One passive sediment trap sample was also collected from the same location as sample 5813 by the MOECC in 2014 (2060). The passive sediment trap consists of four acrylic cylinders set in 2 L plastic beakers in a deployment frame. The trap was deployed approximately 2 m above the lake bottom and captured material falling through the water column from May 26, 2014 to October 23, 2014. Upon retrieval of the sediment trap, the water was drained off and the settled material from each tube was transferred to a 500 mL PET jar.

Twelve sediment samples were collected from six Lake Erie beaches in November 2015, using a split spoon sampler, which recovered sand from the foreshore (between low- and high-water marks) and backshore (high-water mark to inland beach limit) to a depth of 30 cm. Polyvinyl chloride (PVC) liners containing each increment were capped, placed in a cooler and transported to the lab. Sediment samples were also collected from 2 northwestern Lake Erie tributaries

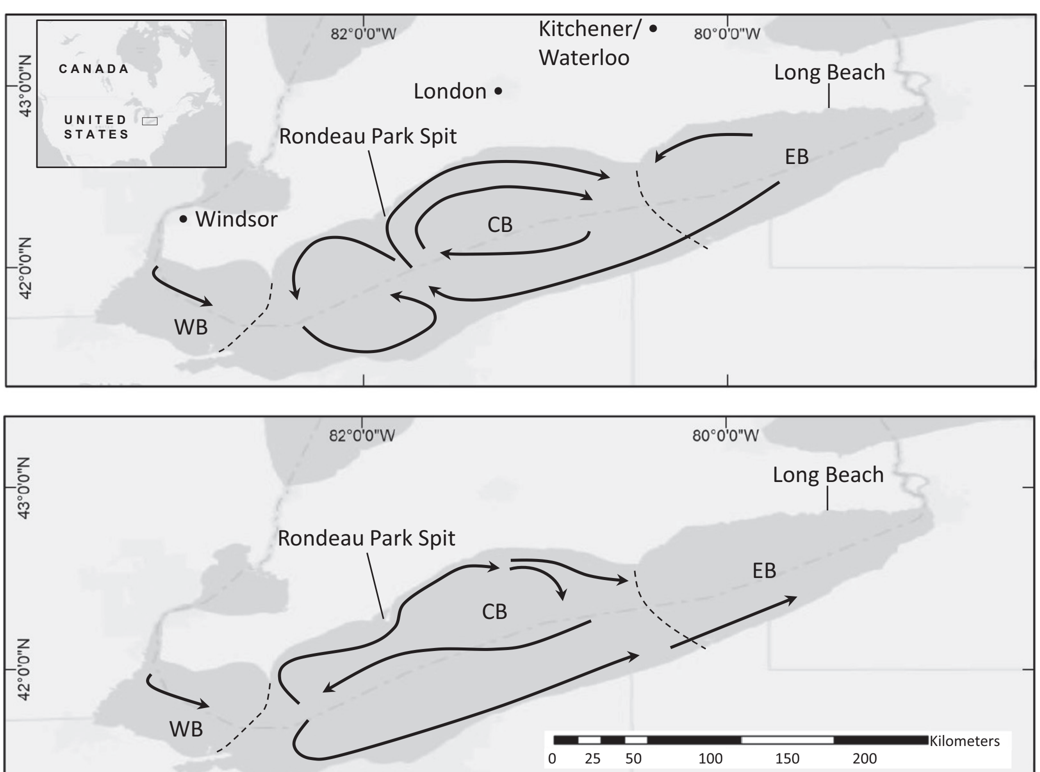

Fig. 1. Maps of Lake Erie displaying surface water circulation patterns from May–October (upper) and November–April (lower). Inset shows location of Lake Erie in North America; WB – western basin, CB – central basin, EB – eastern basin. Surface water circulation patterns from Beletsky et al. (1999).

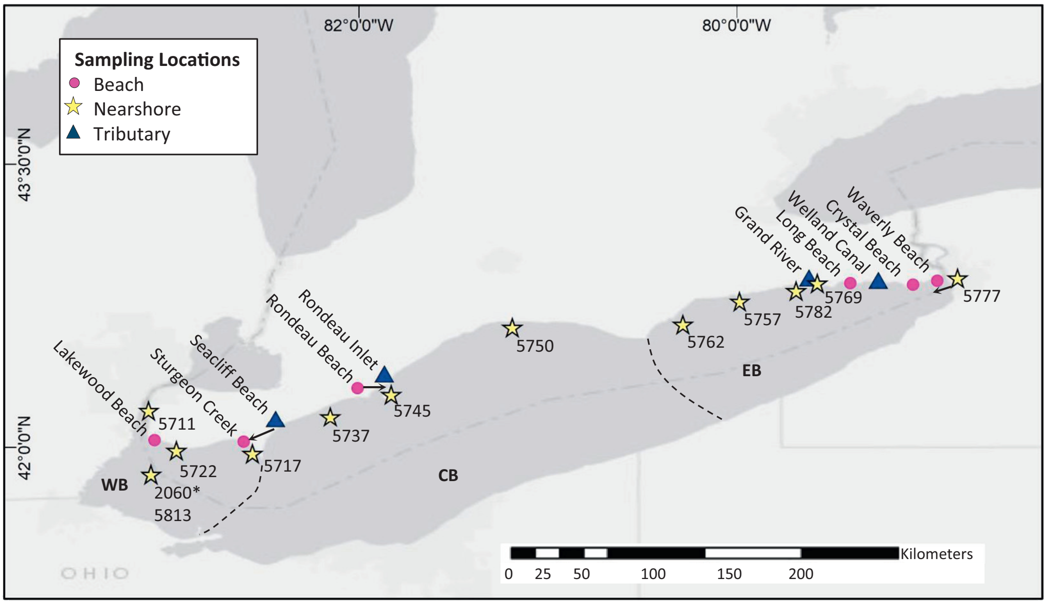

Fig. 2. Sediment sample locations in Lake Erie and its tributaries and beaches.*Sample 2060 is a passive sediment trap sample, whereas all other nearshore (benthic) samples were collected by a Shipek grab sampler. Tributary samples were collected with a petite ponar grab whereas beach samples were collected using a split spoon corer.

(Sturgeon Creek, Rondeau Inlet) and from 2 northeastern tributaries (Grand River, Welland Canal) in November 2015 using a Petite Ponar grab sampler. Two samples were extracted from each location. Once grabbed from the tributary bed, the sediment was deposited into a stainless steel pan and was scooped into a Nalgene® high density polypropylene jar and placed in a cooler for transport.

All samples were thawed at room temperature, emptied onto aluminum pie plates and placed into a drying oven set at 90 °C for 8 h. This temperature ensured that the common polymers PE, PET, PP and PS would not melt while in the oven. It is possible, however, that some PVC particles may have melted because the polymer has a lower melting point of approximately 75 °C. Each sample was wet-sieved to remove the grain fraction <63 μm (silt and clay) and was re-dried for an additional 8 h. The dried sample was weighed and was emptied into 250 mL of sodium polytungstate (SPT) solution with a specific gravity of 1.5 g/cm^3. The samples were magnetically stirred for 1 min and were then poured into a glass separatory funnel to settle. The dense grains were drained into a glass beaker until only floating particles remained in the separatory funnel. The floating particles were filtered from the SPT solution by draining the solution into a beaker fitted with a glass conical funnel lined with VWR® Grade 114 qualitative fast flow 25 μm filter paper. The filter paper was rinsed with reverse osmosis water and drained into a glass petri dish for drying. If the sample contained a large amount of organic material, it was exposed to wet peroxide oxidation according to the procedure outlined by NOAA (2015). Following the processing procedures, each sample was examined using a Nikon SMZ1500 microscope. Microplastics were removed using stainless steel tweezers, were placed onto double sided tape in a glass petri dish, and were counted according to plastic type: fragments, fibers and microbeads. The particles were photographed using a Nikon digital camera DXM1200F connected to the microscope.

Sixty-eight representative particles were selected for compositional analysis by Fourier-transform (FT) Raman spectroscopy and dispersive Raman spectroscopy at the Museum Conservation Services - Smithsonian Institute in Maryland. Detailed methods are provided in Ballent et al. (2016) and Dean (2016). Sixty-one particles were fragments of different forms and roughness, and various colours (white, black, gray, pink, blue, yellow, orange, red, light green, dark green, transparent), 3 were fibers (2 white and 1 pink), and 4 were spherical beads (orange, transparent).

Precautions were taken to minimize contamination of the samples from airborne microplastic particles during processing. Containers were kept covered with aluminum foil during each stage, except while drying in the closed oven. Laboratory surfaces were routinely wiped down, all containers, tools and sieves were thoroughly washed and rinsed with reverse osmosis water before and after each use and all were stored with their openings covered in aluminum foil. Sample containers used in the field were plastic, but they were either cleaned, rinsed and dried with compressed air prior to use or were new and unopened containers. Researchers wore white cotton laboratory coats. Potential airborne microplastic contamination levels during sample processing and examination were tested by placing clean glass petri dishes, 9 cm in diameter, in the drying oven and on the lab bench in the separation laboratory, and on the microscope stage in the imaging laboratory. Although the samples were rarely exposed to the air outside of the oven, airborne contamination levels were determined by visual inspection of each petri dish under the same stereomicroscope used for sediment sample analysis. After 2 h of exposure, the microplastic airborne contamination levels for the oven, bench and microscope were 1, 0 and 0, respectively. Following 24 h of exposure, the levels for the oven, bench and microscope were 3, 1 and 4, respectively. All microplastics that accumulated in the petri dishes were fibers.

Geospatial analysis

Maps of Lake Erie sampling locations were created using ArcMap 10.1. Layers and data were uploaded using the North American Datum 1983. Quaternary-level watershed (river and coastal stream catchment basins) boundary data were acquired from the Ontario Open Data Catalogue, published by the Ministry of Natural Resources and Forestry in April 2015. Population data was acquired from the Statistics Canada 2011 Census Boundary Files for Populations Centre. Where population centres overlapped with multiple watersheds, an algorithm was used to proportionally divide the population amongst each contributing watershed. A review of plastic suppliers in Ontario using ThomasNet.com shows 46 suppliers in the Canadian Lake Erie watershed, with 23% located in the Windsor area, and 17% and 15% located in Kitchener/Waterloo and London, respectively. All three cities are in quaternary level watersheds with the greatest population densities, and therefore, the influence of urban proximity versus plastics suppliers on microplastics abundance could not be determined.

Results

A total of 1178 particles were visually identified as potential microplastics. Thirty-eight of 68 particles analyzed by FT and dispersive Raman spectroscopy displayed little or no signal and composition could not be determined. The difficulties in obtaining a signal may be due to sample colour lightness. For example, of 20 blue particles analyzed, the 5 particles producing a weak signal were dark blue or contained black flecks. Similarly, the black and gray particles analyzed did not produce a signal. One white fragment was too small to be analyzed and a second white fragment was determined to be a shell particle. Two white fibers were identified as cellulose and rayon/cotton. The twenty-eight particles positively identified as synthetic polymers include 17 polyethylene (PE), 8 of which contained the pigment copper (II) phthalocyanine blue (commonly used in paints, inks and plastics); 4 polypropylene (PP) with copper (II) phthalocyanine blue; 2 polystyrene (PS), 2 poly-vinyl chloride (PVC), 2 poly methyl methacrylate (PMMA), and 1 polyurethane (PU). Although the compositions of 38 particles could not be determined using the method, we report microplastic abundances according to those fibers, fragments and beads identified microscopically. It is therefore possible that our abundances are overestimates, particularly for fibers and beads. Fragments were more convincingly plastic based on non-organic colours and non-natural forms.

Microplastics abundance for each sample was normalized to number of particles per kg of dry sediment (kg^{-1}) using the mass of the dried sediment sample following removal of the fraction <63 μm (Table 1). Overall abundances ranged from 0 to 382 kg^{-1} (ave. 96 kg^{-1}) for fragments, 0–681 kg^{-1} (ave. 114 kg^{-1}) for fibers, and 0–24 kg^{-1} (ave. 3 kg^{-1}) for beads. Nearshore samples contained 0–391 kg^{-1} of microplastics, with one nearshore sediment sample (5750) and the suspended solids sample (2060) containing no identifiable microplastic particles (Fig. 3a; Table 1). The nearshore samples containing the greatest number of microplastics were sample ID numbers 5722 and 5813 (155 kg^{-1} and 391 kg^{-1}) from the western basin, and 5769 (126 kg^{-1}) from the eastern basin (Fig. 3a, 4). Approximately 64% of the nearshore microplastics were fibers, whereas 36% were fragments. Fragment sizes ranged from 0.10 mm to 0.50 mm, and were mainly blue, but were also black, red, white and green. Nearshore fibers ranged from 0.16–1.70 mm and were mainly black, but were also pink, purple, red, green and blue. Although concentrations of benthic microplastics along the north shore of Lake Erie were fairly uniform, slightly higher concentrations were evident in samples from the eastern basin near the mouth of the Grand River and from the Western Basin near the mouth of the Detroit River (Fig. 4).

All foreshore and backshore samples from the six beaches contained microplastic debris, with a range of 50 to 146 kg^{-1}. The backshore samples contained a higher concentration of microplastic than the foreshore samples (463 kg^{-1} versus 242 kg^{-1}), except for at Seacliff Beach, where the foreshore sample contained 10 kg^{-1} more than the backshore sample. Averaging the abundances from foreshore and backshore localities at each beach resulted in the greatest number of particles in samples from Long Beach and Rondeau Beach (127 kg^{-1} and 146 kg^{-1}, respectively). Long Beach is located within a bay along the northern shoreline of the eastern basin, and Rondeau Beach is located on a sand spit that protrudes into the central basin of Lake Erie (Fig. 4). The types of microplastics identified included fibers (63%), fragments (37%), and beads (<1%) (Fig. 3b). The fragments ranged from 0.07 mm to 4.0 mm, and were coloured, in order of highest abundance, blue, white, yellow, green, red, pink and orange. Beach fibers ranged from 0.28–3.80 mm and were mainly black, but were also pink, purple, red, green and blue. Beads were amber and 0.4 mm in size.

Tributary samples contained 10–462 microplastics kg^{-1}; the sample containing the most microplastic debris was collected from the Welland Canal (462 kg^{-1}), which drains into Lake Erie's eastern basin. The distribution of microplastic types from tributary samples was: fibers (216 kg^{-1}, 37%), fragments (361 kg^{-1}, 62%), and beads (5 kg^{-1}, 1%) (Fig. 3c). The fragments ranged from 0.15 mm to 2.50 mm. The Welland Canal samples contained larger fragments than the average fragment size from the three other rivers. Fragment colours from river samples, in order of abundance, were blue, white, red, pink, orange and green. One blue fragment was oblong and helical, greatly resembling the fragments described by Ballent et al. (2016) as deflashing material. The most abundant fragment colour in all sampling locations was blue. Tributary fibers ranged from 0.48–3.0 mm and were black, orange, blue and green. Beads were amber and 0.32–0.48 mm in size.

Discussion

The number of microplastic particles identified in the Lake Erie nearshore samples (0–462 kg^{-1}) is significantly less than the number identified in Lake Ontario nearshore samples (40–4270 kg^{-1}; Ballent et al.,

Table 1
Summary of types and abundances of particles identified microscopically as microplastics in sediment sampled from Lake Erie nearshore, tributary and beach sites. Foreshore and backshore samples from each beach are combined.

Sample	Environment	Type	#Fragments/kg^{-1} sed.	#Fibers/kg^{-1} sed.	#Beads/kg^{-1} sed.	#Anthropogenic particles/kg^{-1} sed.
2060	Nearshore	Trap	0	0	0	0
5711	Tributary	S. Grab	9	18	0	27
5717	Nearshore	S. Grab	37	42	0	79
5722	Nearshore	S. Grab	65	90	0	155
5737	Nearshore	S. Grab	62	0	0	62
5745	Nearshore	S. Grab	13	23	0	36
5750	Nearshore	S. Grab	0	0	0	0
5762	Nearshore	S. Grab	59	59	0	118
5757	Nearshore	S. Grab	0	26	0	26
5769	Nearshore	S. Grab	85	41	0	126
5777	Nearshore	S. Grab	8	16	0	24
5782	Nearshore	S. Grab	37	29	0	66
5813	Nearshore	S. Grab	33	358	0	391
Sturgeon	Tributary	P. Grab	33	8	1	42
Rondeau	Tributary	P. Grab	6	4	0	10
Grand	Tributary	P. Grab	42	0	0	42
Welland	Tributary	P. Grab	271	186	5	462
Waverly	Beach	S. Corer	9	51	0	60
Crystal	Beach	S. Corer	23	42	1	66
Long	Beach	S. Corer	6	119	2	127
Rondeau	Beach	S. Corer	55	91	0	146
Seacliff	Beach	S. Corer	31	32	0	63
Lakewood	Beach	S. Corer	40	10	0	50

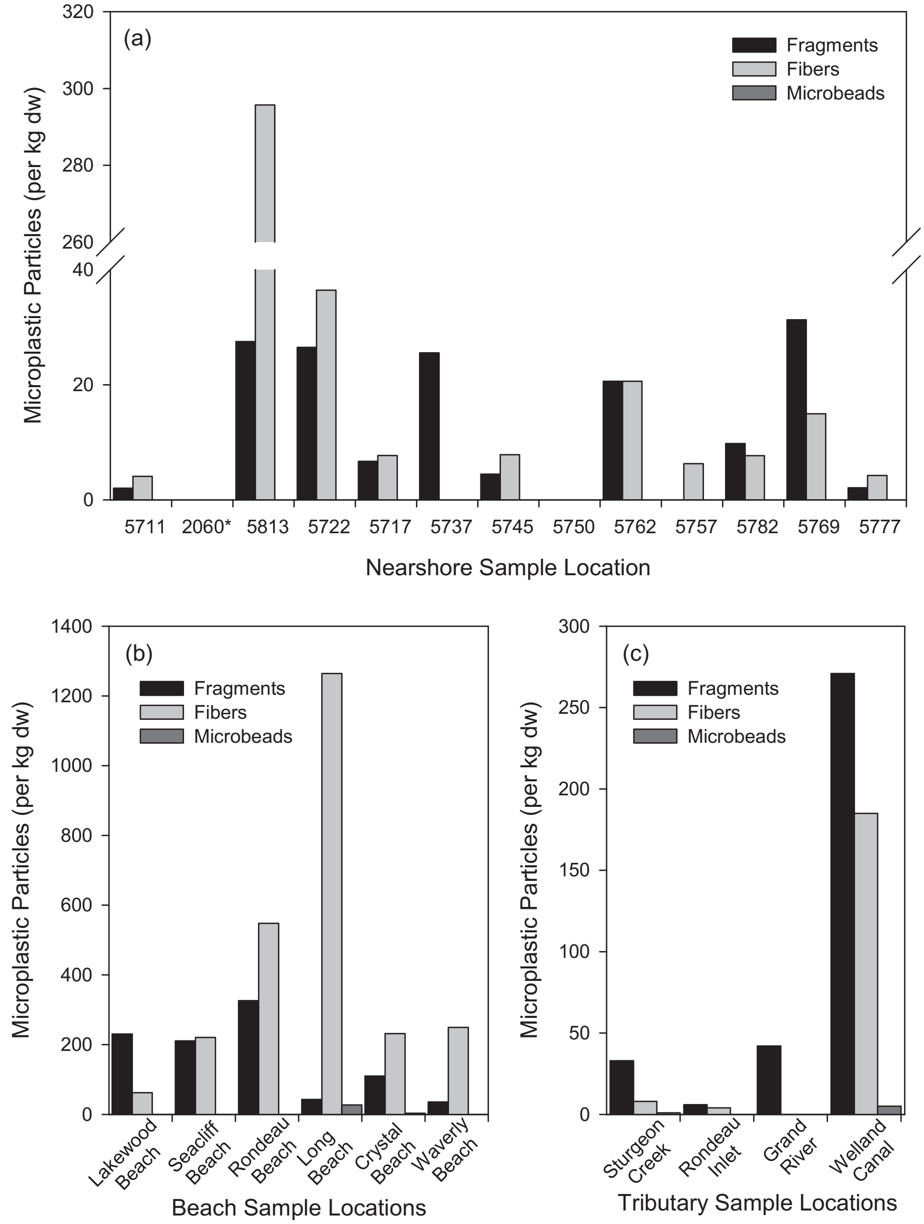

Fig. 3. Abundances and types of microplastics identified from each sample according to site characteristics (A – nearshore; B – beach; C – tributary). Samples along x-axis of panel 3A are arranged from east to west. Fibers were most abundant in nearshore and beach samples whereas fragments were more common in tributary sediments. Foreshore and nearshore samples from each beach have been averaged.

2016). In addition, the sampled Lake Erie tributary sediments contained far lower microplastic counts than those in the sampled tributaries of Lake Ontario (10–462 kg^{-1} versus 40–27,830 kg^{-1}, respectively); removing anomalous sample P-EC2 from Ballent et al. (2016) produces a range of 40–1740 kg^{-1}. The microplastic counts from beach samples were 50–146 kg^{-1} (Erie) and 20–470 kg^{-1} (Ontario). The relative proportions of types, however, are comparable in nearshore, tributary and beach samples, with fragments and fibers being much more abundant than microbeads. On first examination of the results, the greater abundances of microplastics in Lake Ontario sediments could be attributed to its terminal location in the Great Lakes system, wherein debris derived from the Lake Superior, Michigan, Huron, Erie and Ontario watersheds contribute to the microplastic load. Based on their hydrodynamic model of plastic debris transport through the Great Lakes system, Hoffman and Hittinger (2017) predicted that 0.95 t of plastic debris are transported from Lake Erie to Lake Ontario per year. This possibility, however, remains to be verified because the Lake Ontario and Lake Erie field studies focused only on the Canadian shoreline of each lake.

Another possibility for the lower microplastics counts, as well as the relative paucity of microbeads in the Lake Erie samples could be that some samples were subjected to boiled wet peroxide oxidation whereas the Lake Ontario samples were not. Munno et al. (2017) recently reported that boiling the solution to temperatures >70 °C results in the loss of some spherical microbeads. The treatment, however, does not account for the striking differences in abundance of fragments and fibers in samples from the two lakes. In addition, only some samples were subjected to wet peroxide oxidation and the overall number of microbeads was very low (6).

Ballent et al. (2016) showed that the highest concentrations of microplastics in nearshore, beach and tributary samples of Lake Ontario were between the Humber Bay and Toronto Harbour regions, which they attributed to the influence of high population density, significant

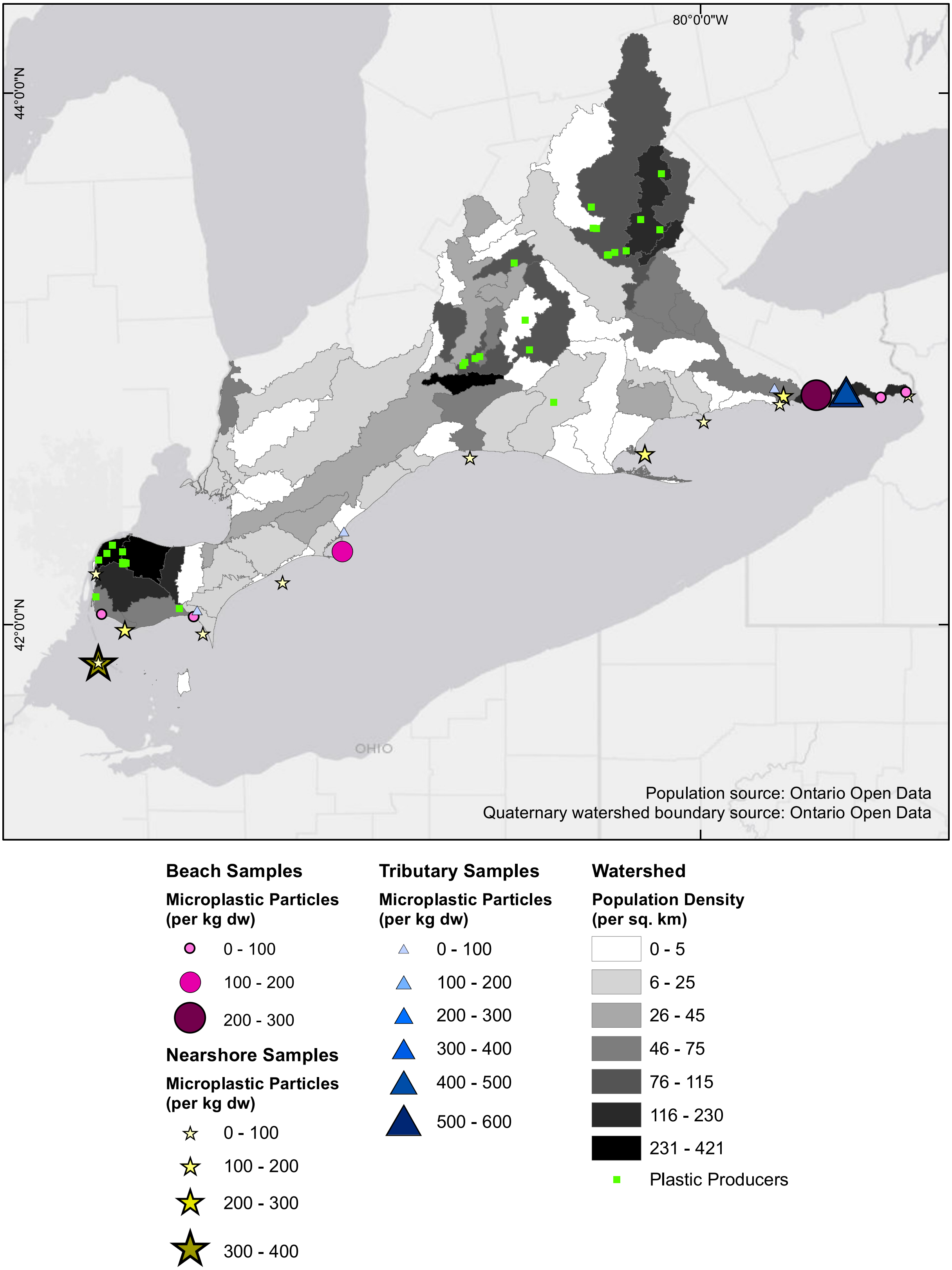

Fig. 4. Microplastics abundance in number per kg of dry weight sediment (kg^{-1}), in nearshore, tributary and beach sediments of Lake Erie relative to population density. The beach sample and tributary sample with the greatest abundances of microplastic are located in the eastern basin, whereas the nearshore sample with the highest number of microplastics is located in the western basin.

plastics-related industrial activity, and shoreline morphology. Bays and harbours are sites of low water energy, allowing for the deposition of microplastic particles. The present Lake Erie study shows that microplastics are mainly concentrated in nearshore sediments of the western and eastern basins, tributary sediments of the eastern basin, and beach sediments of the central basin (Fig. 4). The western basin is the first depositional site into which the Detroit River drains. The city of Detroit had a population of approximately 673,000 in 2016 (United States Census Bureau, 2017), which may explain the greater abundances of microplastics in nearshore sediments in this region. It is interesting that the passive sediment trap sample (2060) contained no microplastics, whereas the grab sample from the same locality (5813) contained 390 kg^{-1}. The timing of sample collection overlaps (Grab, August 2014; Trap, May–October 2014), and therefore, the differences in abundances may be due to depositional processes. The trap collects sediment falling from suspension whereas the grab collects the top 3 cm of sediment on the surface of the lake bottom. This suggests that microplastics >63 μm are being transported by traction rather than suspension processes. Considering that the <63 μm grain size represents silt and clay, which are typically deposited from suspension, removing this fraction from our samples (necessitated by filtration to remove clay) may have eliminated the smaller microplastic particles in the trap sample.

The most populated Canadian quaternary-level watershed that is directly connected to Lake Erie contains the Welland Canal and Grand River. It is possible that the concentration of nearshore and tributary microplastics in the eastern basin compared with the central basin is related to population density, wherein the Grand River watershed is the most populated watershed draining directly into the lake. The high abundance of microplastics in the Welland Canal samples could be related to the input of anthropogenic debris from heavy shipping traffic and/or could be a result of the low water flow velocity through the canal, which is equipped with 8 lift locks. This would promote greater deposition in this region compared to the Grand River where higher discharge rates occur. Low concentrations of nearshore microplastics were mainly found in samples adjacent to watersheds with population densities of <25 per km^2, which may indicate a relationship between microplastics abundance and population density. Cable et al. (2017) sampled surface water triplicates from 22 stations in Lake Erie and its tributaries; the greatest concentrations of plastic were found near urban centres, which is consistent with the nearshore results of the present study. In their study of 29 Great Lakes tributaries, Baldwin et al. (2016) recognized a similar correlation between population density and plastics distribution.

Long Beach and Rondeau Beach contained the greatest number of microplastics of the beaches sampled, and this is likely related to their association with geomorphological features. Long Beach is located within a bay that experiences longshore transport of debris to the west (Fig. 1a). The western terminus of the bay juts into Lake Erie approximately 3.3 km, providing a barrier to continued lake transport of microplastic. Rondeau Provincial Park is located along the east-facing side of a spit that protrudes approximately 9.1 km SSW into Lake Erie, thereby affecting the movement of surface water currents and may effectively act as a "trap" for floating plastic debris (Fig. 1b).

A temporal sampling bias is also possible, as beach, tributary, and nearshore sediments were all sampled at different times: nearshore in August 2014; continuous nearshore from May 2014 to October 2014; northwestern beach quadrats and transects from June 22–29, 2015; northeastern beach quadrats and transects from June 30–July 7, 2015; northeastern beach sediment, tributary sediment, and tributary quadrats on November 14, 2015; and northwestern beach sediment, tributary sediment, and tributary quadrats on November 15, 2015. The majority of the sampling therefore took place during the months of summer surface water circulation, however, sampling of beach sediments, tributary sediments, and tributary quadrats were performed during the months of winter surface circulation.

The hydrodynamic model developed by Hoffman and Hittinger (2017) maps the movement and concentration of low density plastic particles in surface currents of the Great Lakes. Relating population density with plastic input, the authors recognized good correlations between plastic abundances in beach surveys (Zbyszewski et al., 2014) and modeled accumulation for Lake Huron. Their model predicts that for Lake Erie, the greatest concentrations of floating plastic debris should be found in the western basin of Lake Erie, which is not consistent with our beach results. In contrast to the results of Hoffman and Hittinger (2017), Eriksen et al. (2013) identified the eastern basin as containing the highest floating particle counts based on manta trawl results. Cable et al. (2017) suggest that the findings of Eriksen et al. (2013) represent only a snapshot of surface plastic concentrations, which tend to be nonstationary on the order of days, weeks or months. The models from Cable et al. (2017) and Hoffman and Hittinger (2017) are consistent with a greater concentration of surface plastics in the western basin compared with anywhere else in the lake. Through their model, Cable et al. (2017) demonstrate that plastic debris in the western basin mainly enters Lake Erie through the Detroit River and the River Raisin; two tributaries that flow through highly urbanized regions of Michigan. In addition, both models predict a dearth of plastic debris along the northern shoreline, with the majority of the particles entering Lake Erie preferentially accumulating along the southern shoreline. Although the present study focuses on benthic microplastic debris, the generally low abundances of microplastics in our samples may reflect the transport of plastic debris away from the northern shoreline prior to settling.

Conclusion

The presence of microplastic particles in nearshore and tributary sediment of northern Lake Erie indicates that plastic debris is accumulating below the water column and not just near the water surface. Fragments and fibers commonly comprise the benthic component and their distribution reflects a variety of factors, including population density, urban proximity to the lake and its tributaries, and sedimentation patterns in different depositional environments. The overall number of microplastic particles identified in the northern Lake Erie samples is much lower than expected, but may be a function of water currents that preferentially transport and accumulate plastics to the southern shoreline of the lake. This hypothesis can only be tested by sampling nearshore sediment across the entire lake over a short period of time and under consistent weather conditions. The benthic sediment results from Lake Erie and from an earlier study of Lake Ontario should be compared with similar samples from each of the Great Lakes in order to gain a complete understanding of microplastics distribution in sediment throughout the entire system. The results would inform policy-makers of areas of concern regarding potential effects of plastics pollution on organisms and their ecosystems.

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