Hidden plastics of Lake Ontario, Canada and their potential preservation in the sediment record

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ABSTRACT

Microplastics are a source of environmental pollution resulting from degradation of plastic products and spillage of resin pellets. We report the amounts of microplastics from various sites of Lake Ontario and evaluate their potential for preservation in the sediment record. A total of 4635 pellets were sampled from the Humber Bay shoreline on three sampling dates. Pellet colours were similar to those from the Humber River bank, suggesting that the river is a pathway for plastics transport into Lake Ontario. Once in the lake, high density microplastics, including mineral-polyethylene and mineral-polypropylene mixtures, sink to the bottom. The minerals may be fillers that were combined with plastics during production, or may have adsorbed to the surfaces of the polymers in the water column or on the lake bottom. Based on sediment depths and accumulation rates, microplastics have accumulated in the offshore region for less than 38 years. Their burial increases the chance of microplastics preservation. Shoreline pellets may not be preserved because they are mingled with organic debris that is reworked during storm events.

1. Introduction

Plastic debris pollution remains a significant environmental issue because of its persistence on a global scale. Although the sources of plastic items are anthropogenic and thus originate on land, the extent of plastics pollution only became apparent once plastic debris reached Earth's oceans and became more visible in surface waters and along shorelines (e.g. Carpenter and Smith, 1972; Colton et al., 1974; Gregory, 1977; Morris, 1980; Dixon and Dixon, 1983; Ryan and Moloney, 1993; Moore et al., 2001). The dangers of plastic debris in marine environments have been well-documented. Recent examples demonstrating the effects of plastic on marine organisms point to ingestion (e.g. Denuncio et al., 2011; Possatto et al., 2011; Bond et al., 2014; Bravo Rebolledo et al., 2013; Van Cauwenberghe and Janssen, 2014) and entanglement (e.g. Laist, 1997; Sazima et al., 2002; Votier et al., 2011; Yorio et al., 2014) as the major threats. Plastics also assist in the transfer of persistent organic pollutants (POPs) that may travel up the food chain (Endo et al., 2005; Rios et al., 2007; Colabuono et al., 2010; Rochman et al., 2013; Koelmans et al., 2014). In addition, floating plastic debris acts as transport media for encrusting organisms that may become invasive species (e.g. Winston, 1982; Barnes, 2002; Gregory, 2009). In contrast, relatively little is known about plastics pollution in fresh- or mixed-water settings. Characterization and quantification of plastic debris items in rivers (Lechner et al., 2014; Morritt et al., 2014; Rech et al., 2014; Sanchez et al., 2014; Castañeda et al., 2014) and estuaries (Browne et al., 2010; Lima et al., 2014; Yonkos et al., 2014) indicate that these are significant pathways for polymers travelling to larger bodies of water. Plastics accumulation in lakes remains poorly understood because only a minor amount of investigations have been conducted (Zbyszewski and Corcoran, 2011; Faure et al., 2012; Imhof et al., 2013; Zbyszewski et al., 2014; Free et al., 2014; Dreidger et al., 2015; Hoellein et al., 2015), and factors such as seasonal changes in surface water currents, locations of urban centres, and river and wastewater input are amplified by the relatively small size of a lake compared with an ocean.

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The types and distribution of plastics in open water and shoreline regions of the Great Lakes system of North America are relatively unknown. Available results show that polyethylene (PE) and polypropylene (PP) are the most common polymer types (Zbyszewski and Corcoran, 2011; Zbyszewski et al., 2014), the majority of the plastic items are <5 mm in size (Zbyszewski and Corcoran, 2011; Eriksen et al., 2013), and POPs were found sorbed to the surfaces of plastics (International Pellet Watch, 2005–2013; L. Rios, unpublished data). This information was provided through surveys of Lakes Superior, Huron, Erie and St. Clair. However, until 2014, the only available data concerning plastics pollution of Lake Ontario was provided through the Great Canadian Shoreline Cleanup and the Alliance for the Great Lakes Adopt-a-Beach Program. The latter indicates that from September, 2012 to August, 2014, 46% of visible debris items collected from shorelines was composed of plastic (Alliance for the Great Lakes, 2012–2014). Dreidger et al. (2015) combined the Adopt-a-Beach and Great Canadian Shoreline Cleanup data and found that 77–90% of all shoreline debris collected in 2012 was composed of plastic items.

To date, Castañeda et al. (2014) in their investigation of the St. Lawrence River, Canada, are the only researchers who have described microplastics in bottom sediments of a non-oceanic body of water. The primary objective of this paper is to provide quantitative and compositional results of microplastic (<5 mm) debris items sampled from shoreline and lake-bottom sediments of Lake Ontario, Canada (Fig. 1), and to assess their potential for preservation in the current sediment and future rock record.

2. Materials and methods

2.1. Study areas

Lake Ontario is the smallest of the Laurentian Great Lakes with an average depth of 86 m, and a land drainage area of 64,030 km^2 (U.S. Environmental Protection Agency, 2012). The summer (May–October) surface water circulation pattern is mainly cyclonic, whereas during the winter months (November–April), the lake exhibits a two-gyre circulation pattern with cyclonic flow in the south and east, and anti-cyclonic flow in the northwest (Beletsky et al., 1999).

The Humber Bay region, located along the northwest shoreline of Lake Ontario (Fig. 1B), was selected for investigation for three reasons: 1) Humber Bay is proximal to the Greater Toronto area, and previous research has shown that a greater abundance of plastic debris accumulates near industrial centers (Gregory, 1977; Zbyszewski et al., 2014), 2) four tributaries drain into Lake Ontario within 12 km of Humber Bay; rivers and creeks are considered important pathways for the transport of plastic debris into larger bodies of water, and c) the Humber wastewater treatment plant drains into Humber Bay, and recent research suggests that microplastics in wastewater may not be completely removed during the treatment process (Fendall and Sewell, 2009; Eriksen et al., 2013). Two specific sampling sites were selected, which include a beach along the southern end of Humber Bay Park West peninsula (N43°36′49″/W79°23′46″) and a swath along the eastern bank of the Humber River (N43°38′13″/W79°28′36″) (Fig. 1C). In addition to land-based samples, two lake-bottom sediment core samples collected in October, 2013 were provided by Environment Canada. Sample 208 was collected from the Niagara Bar (N43°20′14″/W79°02′10″) and sample 403 was collected from the deeper, north-central part of Lake Ontario (N43°35′12″/W78°14′10″) (Fig. 1B).

2.2. Humber Bay field and laboratory methods

A quadrat measuring 25 m × 4 m on the Humber Bay Park West beach was surveyed for visible plastic debris (Fig. 1D). Sampling of the same beach quadrat was conducted on October 7, October 28 and November 18, 2013, in order to determine tri-weekly accumulation rates. In addition, a 10 m × 2.5 m swath along the bank of the Humber River was surveyed for industrial pellets on October 28 and November 18 (Fig. 1E). At the beach location, all visible debris at the surface and to a depth of 5 cm was collected. Once in the laboratory, the beach samples were sorted into four categories: 1) industrial pellets (microplastics), 2) plastic fragments, 3) intact or near-intact debris, and 4) expanded polystyrene (Fig. 2; Table 1). Fragments were further categorized into sizes of >5 cm, 1–5 cm and <1 cm, and the total number and mass of each type of debris was quantified (Table 1). In addition, industrial pellets were subdivided by colour in order to compare the relative proportions of each colour from the Humber Bay beach and Humber River sites.

Thirty pellets from the Humber Bay and Humber River sites from each sampling date were randomly selected using a sample splitter, then cleaned in distilled water in an ultrasonic bath for 5 min to remove surface soil residue. The pellets were air-dried for 24 h and their compositions were analysed using a DeltaNu Rock-Hound spectrophotometer. The Raman spectrum determined from each pellet was compared to a library containing spectra of known samples of low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), polystyrene (PS) and polyethylene terephthalate (PETE).

2.3. Lake-bottom field and laboratory methods

Lake Ontario bottom sediment core samples were collected from aboard the CCGS Limnos using a mini box corer. Box cores were sub-sampled using polycarbonate tubes (7 cm diameter) and then extruded in 2 cm increments from 0 cm to refusal. Core increments were placed in Nalgene® high density polypropylene jars and frozen immediately for transport to the laboratory. Once in the laboratory, 15 sample increments from each core (depth of 30 cm) were thawed at room temperature, emptied onto aluminium pie plates and placed in a drying oven set to 70 °C for 8 h. The sample increments were sieved into grain size fractions of <0.5 mm, 0.5–0.71 mm, 0.71–0.85 mm, 0.85–1 mm, and >1 mm, in order that the sediment could be handled more easily during density separation. Each of the resultant 150 samples were weighed and then emptied into 250 ml of distilled water in a 700 ml beaker. The sediment was magnetically stirred for 1 min, and allowed to settle for approximately 5 min. Low density floating particles were removed from the water and the remainder of each sample was re-dried at 70 °C for 18 h. Once dried, the remaining samples were then emptied into a 250 ml sodium polytungstate solution with a specific gravity of 1.5 g/cm^3. Following magnetic stirring for 1 min, the sediment was allowed to settle for approximately 10 min. All floating particles were removed from solution and washed using distilled water.

Once dried, floating particles from both separation procedures (densities <1.5) were microscopically analysed. Those particles resembling plastics were removed and placed into vials for analysis by Fourier transform infrared spectroscopy (FTIR) at Surface Science Western, University of Western Ontario. The samples were analysed using the micro attenuated total reflection objective (ATR) on the microscope attachment. The ATR objective has a germanium crystal which limits the analysis to an area approximately 80–100 microns in diameter and to a depth on the order of 1–2 microns.
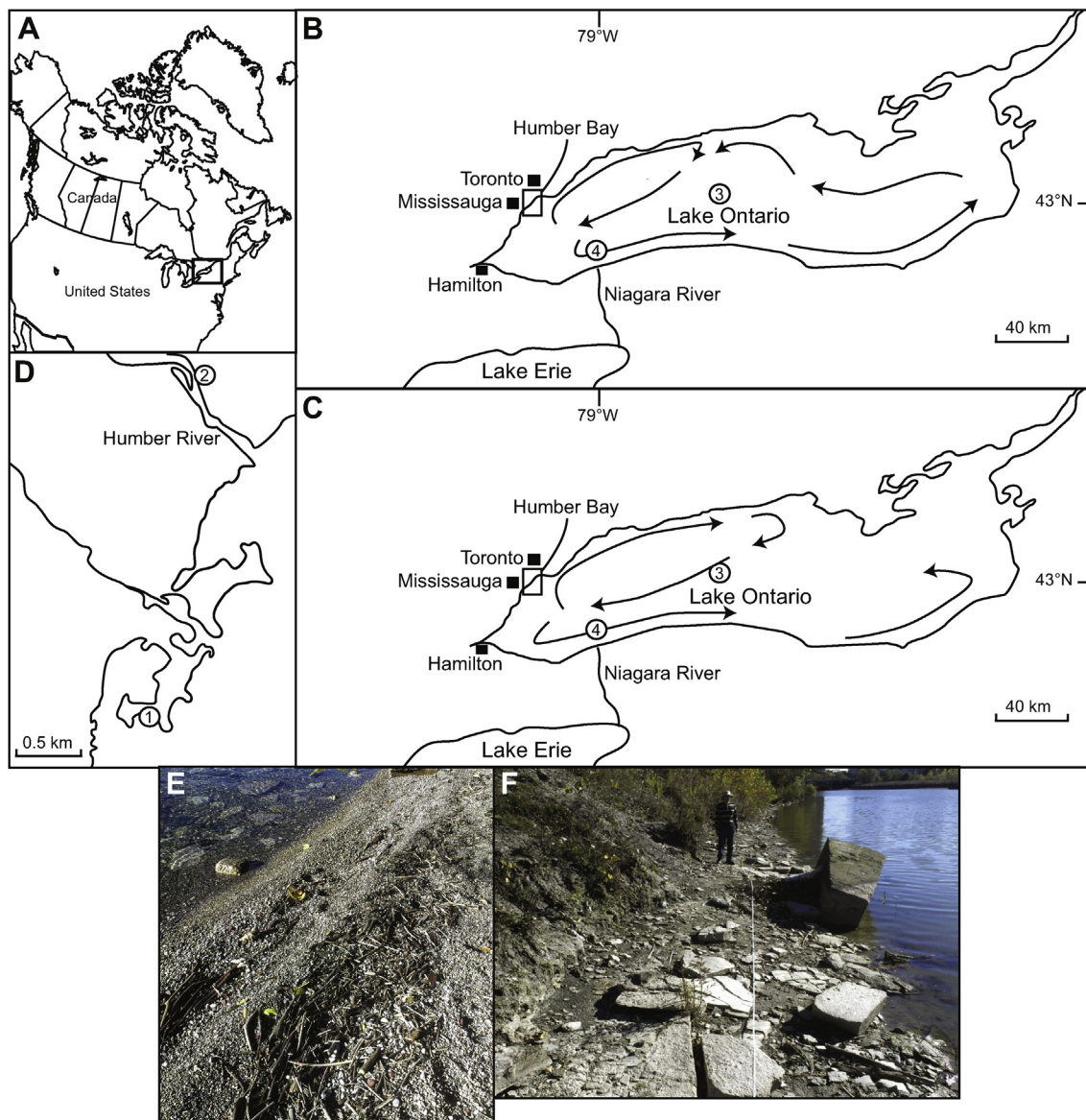
Fig. 1. Location maps of sampling area. A) Location of the Great Lakes in North America. Box indicates Lake Ontario. B) Location of Humber Bay in Lake Ontario with lake bottom sampling sites. 3: Station 403; 4: Station 208. Summer surface water currents from Beletsky et al. (1999). C) Location of Humber Bay in Lake Ontario with lake bottom sampling sites. 3: Station 403; 4: Station 208. Winter surface water currents from Beletsky et al. (1999). D) Location of sampling locations on the Humber Bay peninsula (1) and along the Humber River (2). E) Photo of the organic-rich strandline on the Humber Bay beach site. F) Photo of the Humber River sampling site.

3. Results

3.1. Humber Bay plastics abundance, accumulation and composition

A total of 6172 pieces of plastic debris were collected from the Humber Bay Park West beach site over the course of the sampling period (Fig. 3A). A large quantity of expanded polystyrene was sampled, but was only quantified in terms of mass. Due to the fragility of this type of polymer and the large quantity collected, quantification in terms of number of individual pieces was not practical. Excluding polystyrene, the most common type of debris on the three sampling dates was industrial pellets, with 1634, 2118 and 883 pellets collected on October 7, October 28 and November 18, respectively (Table 1). Fragments were the second most common debris type with a total of 1214 pieces collected. The majority of the pellets and fragments were found within the strandline, as

the accumulated organic material (e.g. wood, weeds) appeared to be extremely effective in trapping small mesoscopic (<10 cm) debris. The intact debris and polystyrene were more widely dispersed across the beach.

The accumulation rates of plastic debris at the Humber Bay beach site were 21.2 pellets, 4.5 fragments, 0.8 intact items and 1.7 g of polystyrene per m^2 over the period from October 7–October 28. From October 28–November 18 the accumulation rate was 8.8 pellets, 3.6 fragments, 1.0 intact items and 1.3 g of polystyrene per m^2. At the Humber River site, 104 pellets were collected on October 28, and 160 were collected on November 18.

The relative proportions of pellet colours found at the beach and river sites on October 28 and November 18 were compared. Although the proportions of different colours from the two sites were not found to be statistically similar, the same colours were identified at both sites (Fig. 3B). Analysis of the Raman spectra determined from the pellets showed compositions of either PE or
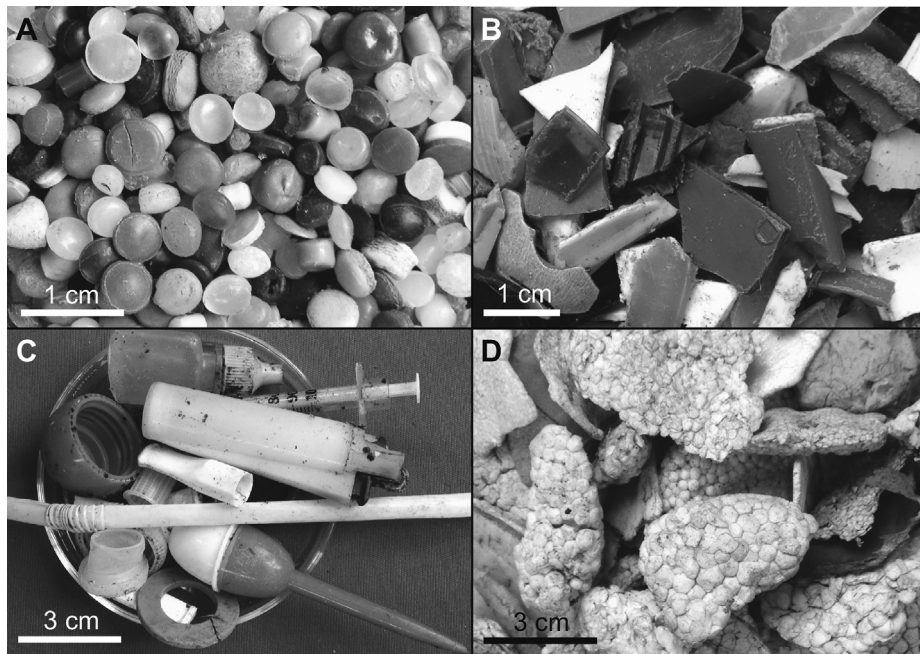
Fig. 2. The four categories of plastic debris found on the Humber Bay beach site: A) Pellets, B) Fragments, C) Intact and near-intact debris, and D) Polystyrene.

PP. Of the pellets analysed from the Humber Bay Park West site, 73.5% of the total number were PE, and 26.5% were PP, whereas the Humber River site contained 95% PE and 5% PP.

3.2. Lake-bottom plastics abundance and composition

A total of 35 pieces of microplastic were identified from the samples analysed. No microplastics were found in samples

Table 1
Characteristics of plastic debris sampled from the Humber Bay Park West and Humber River sites. Data shown includes proportions of plastic type and size, in addition to colour of industrial pellets.

	Oct. 7	Oct. 28	Nov. 18
Humber Bay debris type (number per m²/mass per m²)			
Pellets	16.34/0.42 g	21.18/0.54 g	8.83/0.23 g
Fragments	4.05/1.73 g	4.49/2.24 g	3.60/5.02 g
Intact/N.I.	1.41/4.10 g	0.83/1.50 g	0.99/2.90 g
Polystyrene (mass only)	2.40 g	1.70 g	1.30 g
Humber Bay fragment size total number/total mass			
<1 cm	55/2.48 g	71/2.86 g	34/1.94 g
1–5 cm	321/122.90 g	339/114.93 g	285/172.78 g
>5 cm	29/47.60 g	39/106.70 g	41/327.27 g
Pellet Colour (Humber Bay)			
White/translucent	934	1353	518
Light grey	144	95	59
Dark grey/black	227	265	91
Green	145	254	128
Blue	137	99	73
Pink/Purple	27	24	7
Other	20	28	7

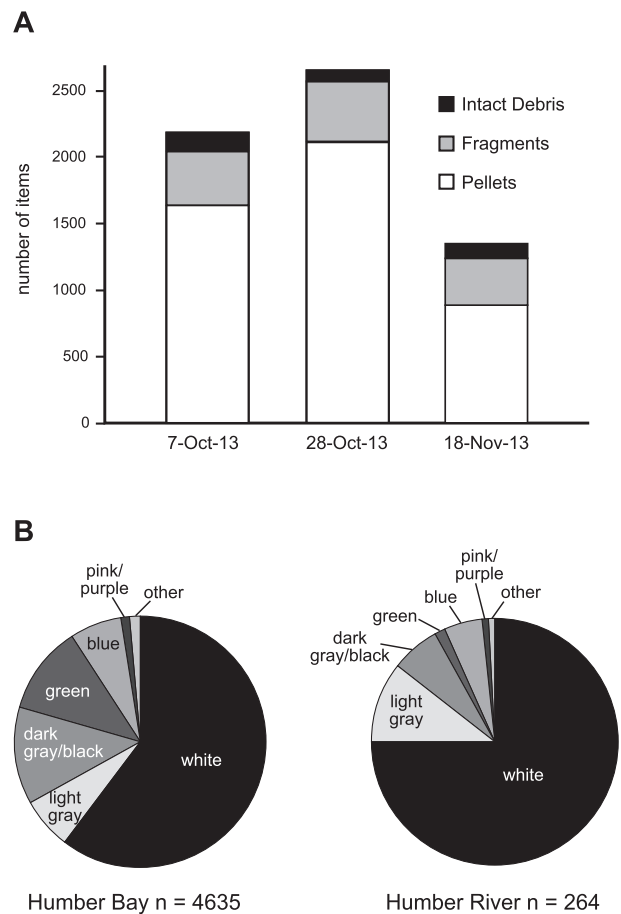| Pellet Colour (Humber river)	Oct. 28	Nov. 18
White/translucent	83	115
Light grey	11	17
Dark gray/black	1	16
Green	2	2
Blue	5	8
Pink/Purple	0	2
Other	1	0

Fig. 3. Bar and pie graphs showing: A) the proportions of different types of plastic debris along the Humber Bay beach site on three different dates, and B) the overall colours of pellets collected from the Humber Bay beach and river sites.

Table 2
Number of microplastic particles counted from each sample increment in box cores from Stations 208 and 403. Increments at depths >8 cm did not contain any plastic.

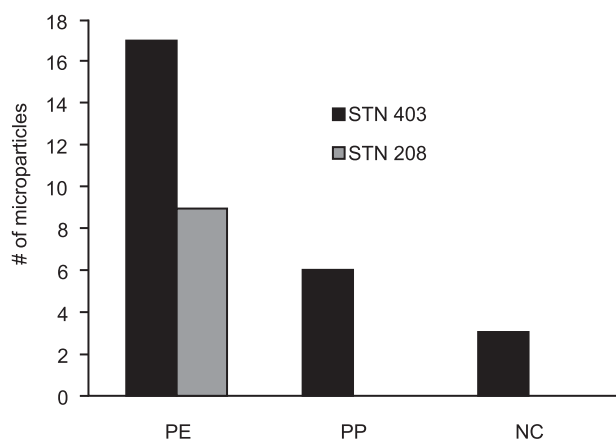| Sampled slice	Station 403	Station 208
0–2 cm	9 particles	5 particles
2–4 cm	9 particles	2 particles
4–6 cm	3 particles	1 particle
6–8 cm	5 particles	1 particle

Fig. 4. Relative abundance of particles composed of PE, PP and NC found in Lake Ontario bottom sediments at Stations 208 and 403. Note that PE is the predominant type of polymer, which is in agreement with the results from Humber Bay.

collected from sediment depths >8 cm. Based on palynological and radiogenic dating, sediment accumulation rates in Lake Ontario during the last ca. 160 years range from 0.1 to 0.4 cm/year, depending on location (Kemp et al., 1974; Robbins et al., 1978; Wong et al., 1995). Kemp et al. (1974) determined an accumulation rate of 0.21 cm/yr from a location proximal to that of Station 403 (Fig. 1B), suggesting that microplastics began to accumulate in the centre of the lake approximately 38 years ago. However, Wong et al. (1995) determined a sedimentation rate of 0.43 cm/yr from a core sampled near Station 403. The latter sedimentation rate would suggest that microplastics have been accumulating in the lake centre during the last 18 years. The variations in sediment accumulation rates may be attributed to the incidence of storm events, as suggested by Kemp and Harper (1976) for different rates determined from different regions of the lake, or could be a function of increased erosion and input of sediment into the lake (which could be related to storm abundance and intensity). The most abundant counts of microplastics in the present study are in the most recent sediment increments (Table 2).

The samples from Station 403 contained more microplastic particles than those from Station 208, with 26 and 9 pieces, respectively (Fig. 4). Of a total dry weight of 42.235 g from Station 403 (samples from <8 cm depth), 0.013 g (0.03%) was composed of microplastics. In contrast, samples collected from <8 cm depth from Station 208 comprised a total dry weight of 103.241 g, 0.010 g of which was composed of microplastics. In addition, no microplastics from Station 208 were found floating in distilled water following magnetic stirring. The 9 microplastic particles from this station were all found floating in the higher density, sodium

Table 3
Characteristics of microplastics sampled from Lake Ontario bottom sediments. The sample numbers represent the station number (208, 403), the depth fraction (e.g. 0–2 cm) and high (HD) and low (LD) density particles. n.d.: not determined.

| Microplastic sample	Colour	Texture	Composition
208 0-2 1HD	Pink	Wispy	PE
208 0-2 3HD	Light blue with brown inclusions	Irregular	PE
208 0-2 3bHD	Pink	Rounded and wispy edges	PE
208 0-2 4HD	Pink with brown inclusions	Wispy	PE
208 0-2 4bHD	Yellow-brown; brown inclusions	Angular	PE
208 2-4 3bHD	Pink with brown edges	Irregular	PE + inorganic
208 2-4 5HD	Pink	Wispy	PE
208 4-6 2HD	Pink	Rounded	PE
208 6-8 1HD	Pink	Irregular	PE
403 0-2 2LD	Pale yellow	Angular; bladed	NC
403 0-2 5LD	Black	Irregular; frayed edges	PE + $CaCO_3$+SiO_2+mica
403 0-2 5bLD	n.d.	n.d.	PP
403 2-4 1bLD	n.d.	n.d.	PP
403 2-4 3LD	Black	Corrugated; frayed edges	PE
403 2-4 3bLD	Black	Angular; corrugated	NC
403 2-4 4LD	White/translucent	Irregular	PP + SiO_2
403 4-6 5LD	Light blue	Irregular	PE
403 4-6 5cLD	n.d.	n.d.	PP
403 6-8 2bLD	Black	Angular	PP
403 6-8 4LD	Pink	Wispy	NC
403 0-2 2HD	Light blue with brown edges	Irregular	PE
403 0-2 4HD	Black	Wispy	PE
403 0-2 4bHD	Light blue	Wispy	PP
403 0-2 4cHD	n.d.	n.d.	PE
403 0-2 5HD	Light blue	Irregular	PE
403 0-2 5bHD	n.d.	n.d.	PE
403 2-4 2HD	Pink	Wispy	PE
403 2-4 3bHD	Gray with translucent edges	Angular	PE
403 2-4 4bHD	Brownish-black	Rounded; scaly	PE
403 2-4 5HD	Pink with brown inclusions	Wispy	PE + inorganic
403 2-4 5bHD	Pink	Wispy	PE
403 4-6 2HD	Pink with brown inclusions	Wispy	PE
403 6-8 1HD	Light blue with brown inclusions	Wispy	PE + inorganic
403 6-8 3HD	n.d.	n.d.	PE
403 6-8 5HD	Light blue with brown inclusions	Wispy	PE + inorganic
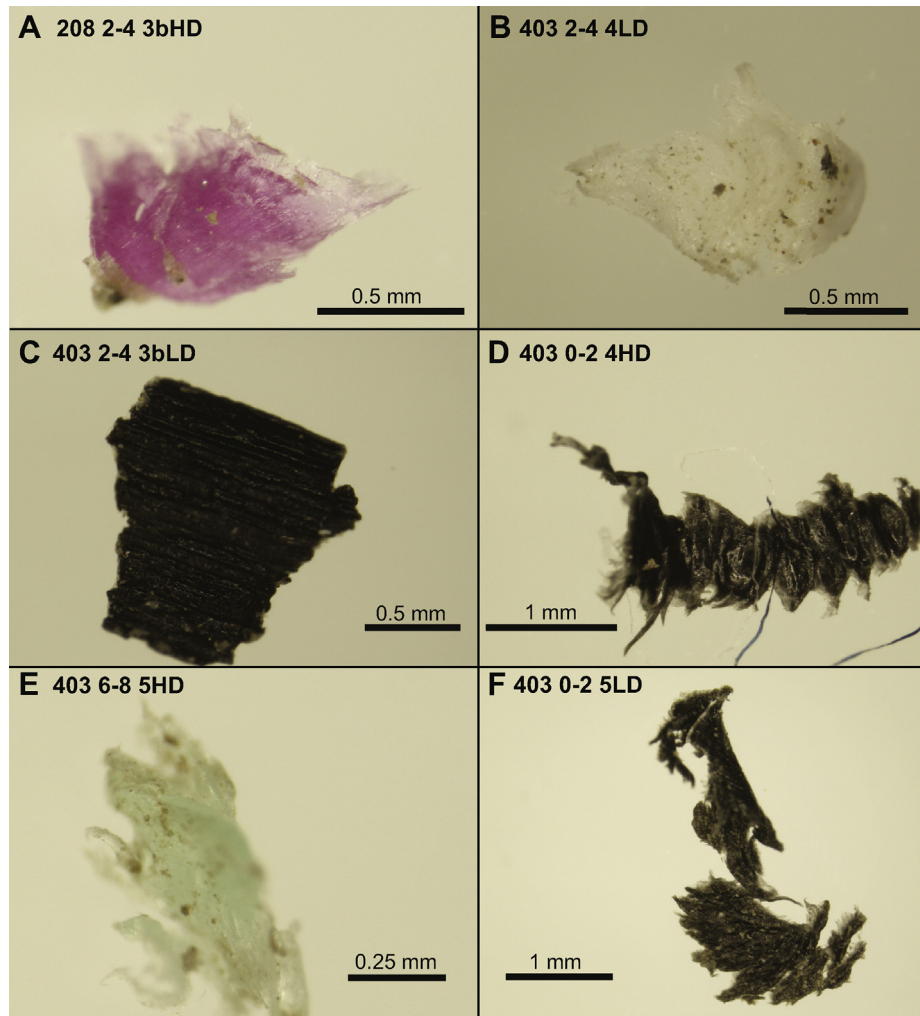
Fig. 5. Photographs of microplastics found in lake bottom sediment samples. Note the presence of brown spots in A, B, and E, which possibly represent mineral fillers. A) Pink, irregular particle composed of PE and an inorganic, B) White to translucent, irregular particle composed of PP and silica, C) Black, angular particle with corrugated surface composed of NC, D) Black, wispy particle composed of PE, E) Light blue, wispy particle composed of PE and an inorganic, F) Black, frayed particle composed of PE, $CaCO_3$, SiO_2 and mica.

polytungstate solution (Table 3).

The microplastic particles ranged from 0.5 to 3 mm in size, and the colours and shapes of the particles from both stations were similar (Fig. 5). Particle colours collected from the low density solution included pink, brown, white, blue, and black, whereas stirring the high density solution resulted in flotation of black particles only. Particle shapes ranged from thin, wispy and film-like to thicker, angular and fragmented (Fig. 5; Table 3).

Analysis of the samples by FTIR spectroscopy shows that PE accounts for the majority of the microplastics with 74% of the total (Fig. 4; Table 3). Polypropylene and nitrocellulose (cellulose nitrate; NC) comprise 17% and 9% of the samples, respectively. Although 29 particles are composed of a single polymer, 6 particles contain a mineral-polymer mixture. The spectra from 2 samples are most consistent with the minerals calcium carbonate ($CaCO_3$), silica (SiO_2) and mica ($XY_{2-3}Z_4O_{10}$ (OH, F)$_2$ wherein X = K, Na, Ba, Ca, Cs, H_3O, NH_4; Y = Al, Mg, Fe^{2+}, Li, Cr, Mn, V, Zn; Z = Si, Al, Fe^{3+}, Be, Ti) (Fig. 6). Four additional samples contained a polymer-inorganic particle mixture, but identification of the inorganic material was not possible based on FTIR spectra alone (Table 3).

4. Discussion

4.1. Tributaries as transport pathways

The quantity of plastic debris per unit area along the Humber Bay beach site is the second highest observed on any Great Lakes beach surveyed to date, with the initial survey yielding 21.8 items/m^2 (excluding polystyrene). The 16.3 pellets/m^2 collected were exceeded only by the 34 pellets/m^2 collected from Sarnia Beach along the Lake Huron shoreline (Zbyszewski et al., 2014). An average of 10.5 pellets/m^2 was collected from the Humber River site, and while sampling, we observed several pellets floating along the surface of the river towards the outlet into Lake Ontario. In addition, the similarity in pellet colours from both Humber Bay sampling locations indicates that the Humber River acts as a transport pathway for pellets into Lake Ontario. There are several smaller tributaries in this area, including Mimico Creek, which flows into Humber Bay along the north shore of the Humber Bay Park West peninsula, and Etobicoke Creek, which discharges into Lake Ontario approximately 6 km south of the Humber Bay site. These tributaries flow through areas of high industrial activity, with several manufacturers of plastic items located within their
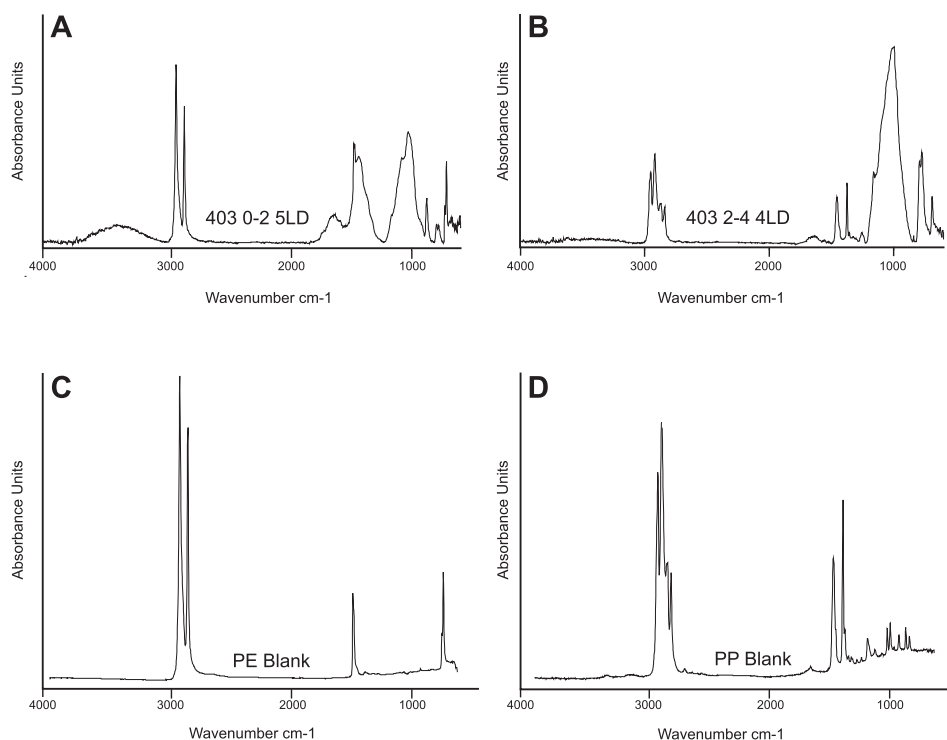
Fig. 6. FTIR spectra of two microplastic particles from lake-bottom sediments. A) Peaks at wavenumbers 2916, 2849, 1471 cm^{-1} and the pair at 729 and 717 cm^{-1} belong to PE. The peaks at 1432 and 877 cm^{-1} are consistent with calcium carbonate. The peak near 1029 cm^{-1} is consistent with mica, and the peaks near 797 and 694 cm^{-1} are consistent with silica. B) Peaks at wavenumbers 2951, 2919, 2869, 2838, 1456, 1377, 1358, and 841 cm^{-1} belong to PP, and the remainder of the peaks at 1162, 999, 795, 775 and 694 cm^{-1} are most consistent with quartz. C) FTIR spectrum from a polyethylene (PE) blank, D) FTIR spectrum from a polypropylene (PP) blank.

respective watersheds. The Humber Bay beach site pellets and the microplastics found in lake-bottom sediments at Stations 208 and 403 could have also been derived from tributaries surrounding the entire lake. Considering the cyclonic (summer) and two-gyre (winter) surface current circulation in Lake Ontario, plastics flowing into the lake could have been transported near the water surface for considerable time prior to deposition.

4.2. Effects of weather conditions

Greater rainfall events promote increased flow rates in tributaries, resulting in greater abundances of plastic debris reaching the lake over shorter periods of time. The first sampling day (October 7) produced a lower quantity of plastic debris than sampling three weeks later on October 28. This 3 week period saw greater amounts of precipitation, as well as higher recorded flow volumes in the Humber River. In addition, the Humber Bay beach site is a high energy environment, with prevailing wind patterns blowing almost directly onto the shoreline. Combined with abundant organic debris washing on shore, pellets are rapidly buried. Similarly, the greater quantity of pellets observed on October 28 compared with November 18 reflects a decrease in precipitation rate. Only one major precipitation event occurred during the second 3 week sampling interval, on November 17. Even if considerable plastic debris was transported into Lake Ontario during this overnight storm, the plastic may not have had time to be deposited onto the beach at Humber Bay before sampling on the morning of November 18.

4.3. Effects of sample location

The Humber River watershed is the largest in the Toronto region

(Toronto Regional Conservation Authority, 2014). The main channel of the Humber River originates in the Niagara Escarpment, and flows 126 km to its discharge point into Humber Bay, mainly through rural and urban areas. The discharge point represents the outflow of approximately 1800 km of waterways, and the area covered by the watershed is home to a population of 856,200 people (Toronto Regional Conservation Authority, 2014). This makes it a major transport pathway for plastic litter into Lake Ontario and especially onto the neighbouring Humber Bay Peninsula.

The greater abundance of microplastics in sediment collected from Station 403 compared with 208 is probably a function of station location within the lake. Station 208 is located near the outlet of the Niagara River, whereas Station 403 is located near the center of the lake (Fig. 1B). Sediment and contaminant accumulation rates are greater within offshore depositional basins in Lake Ontario, compared with inshore locations (Marvin et al., 2003). The approximately 10° slope off of the Niagara Bar generally inhibits the deposition of sediment (Charlton, 1983). In addition, Niagara River water empties as a plume that is diverted to the right (east). Based on an investigation by Horner-Devine et al. (2008), suspended particles can be retained in the plume for up to 18 km distance from shore, within which Station 208 is located. Therefore, it is unlikely that much microplastic debris will sink and accumulate within this region. In addition, particles that settle out on the Niagara Bar have the potential to become resuspended because the plume depth is similar to the depth of the lake water in the near-shore region (Horner-Devine et al., 2008). In contrast, Station 403 is located at least 25 km from land, where no plumes exist and surface currents are weaker.

4.4. Compositions of microplastics

Microplastic samples from Humber Bay and Lake Ontario

bottom sediments were analysed using a combination of Raman spectroscopy and FTIR due to availability of the instruments and cost. Notwithstanding, both are viable methods for determining the compositions of polymers (Nishikida and Coates, 2003). In total, 149 particles were composed of PE, 33 were composed on PP and 3 were composed of NC. The greater number of PE compared with other polymer types is consistent with results from Lakes Huron and Erie (Zbyszewski et al., 2014), as well as from 30 beaches on 5 continents, which indicate a greater abundance of PE compared with PP (Ogata et al., 2009). These results are commensurate with the relative production rates of different polymer types in the United States, with PE being the most produced polymer by weight (American Chemistry Council, 2013).

At the Humber Bay and Humber River shoreline sites, the abundance of PE and PP compared with other polymers can be attributed to their low density, which results in flotation, transport and subsequent deposition along the shore. However, the presence of PE and PP in lake-bottom sediments is surprising, but may be explained in part by the presence of functional fillers that are used to enhance the properties of a polymer and make it more cost-effective (Sekutowski, 1992). Fillers can increase the impact and structural strength, improve scratch resistance, help remove moisture, control viscosity, provide brightness and better colour, and reduce plate-out in plastics (Mathur and Vanderheiden, 2001). In addition to other additives, these fillers include calcium carbonate, silica, kaolin, talc, and mica, some of which were identified in our lake bottom samples (Table 3; Fig. 6). In addition, the additives in the microplastics from Lake Ontario appear spherical (Fig. 5), which is the preferred shape of fillers in order to retain the anisotropic properties of the material (Mathur and Vanderheiden, 2001). It may also be possible that the minerals adsorbed to the surfaces of the polymers while in the water column or on the lake bottom. Clays are layered silicates that have a negative charge on the surfaces of their silicate layers. This allows clay minerals to interact with polymers through adsorption. The third type of polymer identified and restricted to lake-bottom sediments was nitrocellulose, which is consistent with its high relative density of 1.66 compared with water.

Many of the microplastic particles found in the lake-bottom sediment did not show evidence of mineral interactions. Considering that these particles are composed of PE and PP, and therefore have densities less than water, their sinking through the water column must be attributed to alternate processes. Biofouling of plastics has been suggested as a possible mechanism that results in neutral buoyancy of the polymer (Ye and Andrady, 1991; Moore et al., 2001). Moret-Ferguson et al. (2010) found that plastics recovered from the Atlantic Ocean showed higher densities than their virgin plastic counterparts, which led the authors to suggest that biofouling was responsible for the density change. Lobelle and Cunliffe (2011) attached PE plastic bags to boards suspended 2 m below the water surface along the shoreline of Plymouth, UK. Following 3 weeks of submersion, the density of the bags increased as a result of attached biofilms. Recent investigations by Hoellein et al. (2014) and McCormick et al. (2014) show that colonization of microplastics by microbial biofilms can occur in the Great Lakes watershed. Therefore, it is conceivable that biofouling could have played a role in increasing the density of microplastics in Lake Ontario.

4.5. Potential for preservation

The preservation of microplastics in Lake Ontario bottom sediment to depths of 8 cm indicates that plastics have been accumulating over the past ca. 38 years. The greater amount of particles in the uppermost sample increments is commensurate with increasing production and decreasing recovery of plastic items over time. Although the particles identified are on the order of 0.5–3 mm in size, it is unlikely that they will degrade to a smaller size once buried. The estimated persistence of plastic in the environment is in the range of tens to hundreds of years, but degradation would be much slower where plastics are buried under sediments because they become shielded from UVB radiation (Gregory and Andrady, 2003). Continued accumulation of sediment will lead to greater depths of plastic burial, increased compaction, and diagenetic modification (e.g. cementation, reduction of porosity) of loose sediment to consolidated material. Therefore, the potential for preservation of lake or ocean bottom plastics is good.

Abundant pellets identified along the beach of Humber Bay Park west may have potential to become preserved, but we feel this is unlikely. Unlike the lake bottom microplastics that were buried in sediment, the pellets were mainly trapped in organic debris along the strandline, which in places was located at the back of the beach. During high wave activity, this organic debris may be carried back out to the lake and transported elsewhere. Although the overall abundance of pellets was notable (4635 pellets over a 9 week period) during the Fall of 2013, we visited the sampling site in August, 2014 and found no evidence of pellets nor organic debris. This indicates that the abundance of pellets is highly dependent on the movement of organic debris throughout the lake system.

5. Conclusion

This study showed the abundance, accumulation rates, and compositions of microplastic particles from 4 sampling sites in Lake Ontario. The accumulation of industrial pellets along the shoreline of Humber Bay was dependent on weather conditions and the presence of beached organic debris along the strandline. More pellets accumulated on the beach following a period of increased rainfall events than following fair-weather conditions. Increased precipitation led to higher flow volume in the tributaries flowing into the lake, and these tributaries transported pellets from industrial areas as evidenced from on-site observations and similarities in pellet colours found on the beach and along the riverbank. Organic debris traps plastics as they are floating in the water column or after they reach the shore where they accumulate in the strandline. If this organic material is washed back into the lake, the potential for preservation of pellets in the future rock record remains low.

Our investigation is the first to show that microplastics are accumulating within bottom sediments of Lake Ontario. Although the compositions of these microplastics are mainly PE and PP, the interaction with minerals, either as fillers or through adsorption, may account for their ability to sink through the water column and eventually become buried. Given the sediment accumulation rates in the center of Lake Ontario, the microplastics identified in this study began accumulating less than 38 years ago and will continue to be buried until they have greater potential to lithify and become part of the rock record.

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