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Microplastic pollution in the surface waters of the Laurentian Great Lakes

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ABSTRACT

Neuston samples were collected at 21 stations during an ~700 nautical mile (~1300 km) expedition in July 2012 in the Laurentian Great Lakes of the United States using a 333 μm mesh manta trawl and analyzed for plastic debris. Although the average abundance was approximately 43,000 microplastic particles/km^2, station 20, downstream from two major cities, contained over 466,000 particles/km^2, greater than all other stations combined. SEM analysis determined nearly 20% of particles less than 1 mm, which were initially identified as microplastic by visual observation, were aluminum silicate from coal ash. Many microplastic particles were multi-colored spheres, which were compared to, and are suspected to be, microbeads from consumer products containing microplastic particles of similar size, shape, texture and composition. The presence of microplastics and coal ash in these surface samples, which were most abundant where lake currents converge, are likely from nearby urban effluent and coal burning power plants.

1. Introduction

Plastic pollution is the dominant type of anthropogenic debris found throughout the marine environment (Barnes et al., 2009; Gregory and Ryan, 1997). Floating plastic debris, including microplastics, have been reported in the subtropical gyres since the early 1970s in the North Atlantic (Carpenter and Smith, 1972; Colton et al., 1974; Law et al., 2010), North Pacific (Day et al., 1990; Moore et al., 2001), South Pacific (Eriksen et al., 2013), and outside the subtropical gyres in near shore environments (Thompson et al., 2004; Thiel et al., 2013; Dubaish and Liebezeit, 2013).

These plastic debris can be found in high densities and can have far ranging impact on marine ecosystems. Though other types of debris are found in the marine environment, such as glass floats, bottles and light tubes, metal cans and derelict traps, and nets and line, 60–80% is estimated to be petroleum-based plastic (Derraik, 2002; Thompson et al., 2004; Browne et al., 2010, 2011). Plastic marine pollution has the potential to transport non-native species beyond their historical geographic range (Astudillo et al., 2009; Barnes and Fraser, 2003; Bravo et al., 2011; Gregory, 2009; Webb et al., 2009). A wide range of marine life are impacted by plastic pollution through entanglement or ingestion, including marine mammals, birds and reptiles (Laist, 1987; van Franeker et al., 2011), as well as through the persistent organic pollutants that sorb onto the plastic (Mato et al., 2001; Teuten et al., 2007, 2009; Rios et al., 2010). The Convention on Biological Diversity summarized there are currently 663 species of marine life that are known to be impacted by marine debris (Convention on Biological Diversity, 2012).

Plastic pollution may enter waterways through drainage systems, sewage treatment overflow during high-volume rain events (EPA, 2007; Browne et al., 2010; Browne et al., 2011), or can blow off beaches or developed structures, like docks and piers (Ryan et al., 2009). Microplastics may form on land by UV degradation and fragmentation (Andrady, 2003; Thompson et al., 2004; Cole et al., 2011) or road abrasion of larger plastic items through damage by vehicles and transport along concrete pathways, but may also enter the aquatic environment through direct release (Browne

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et al., 2010). Polyethylene and polypropylene microbeads, used in many consumer facial cleansers, have been identified as potential contributors to marine pollution (Gregory, 1996; Fendall and Sewell, 2009). Textile laundering facilities are also potential sources of microplastic fibers (Browne et al., 2011), and microplastic particles from sandblasting media have been suspected to pollute the marine environment since the early 1990s (Zitko and Hanlon, 1991).

Despite the ubiquitous nature of plastic pollution within the open-waters of the world's oceans, data describing microplastic abundance in the Laurentian Great Lakes has been limited to beach surveys (Zbyszewski and Corcoran, 2011). Given that the watersheds surrounding the Great Lakes are heavily urbanized (including the cities of Chicago, Milwaukee, Detroit, Cleveland and Buffalo in the United States, and Toronto in Canada), flow into the St. Lawrence River and ultimately to the North Atlantic Ocean, the lakes represent an important, potential upstream source of plastic pollution into the North Atlantic Gyre. We report here the first open-water survey for plastic pollution within the Laurentian Great Lakes system.

2. Materials and methods

To explore the presence and distribution of plastic pollution in the Laurentian Great Lakes, an expedition aboard the U.S. Brig Niagara was jointly organized between the 5 Gyres Institute[6] and SUNY Fredonia. The 3-week expedition began on 11 July 2012 from Munising, Michigan, sailed Lakes Superior, Huron and Erie before ending on 31 July 2012 in Erie, Pennsylvania. Five samples were collected in Lake Superior, while 8 samples each were collected in lakes Huron and Erie. The sea state on the Beaufort Scale remained between 1 and 3 for all sample sites. The 21 sample sites were not equidistant, but samples were each 60 min long, timed using a stopwatch, and the tow speed was kept to 2.0 knots. All samples were preserved with 70% isopropyl alcohol.

Samples were collected using a manta trawl with a rectangular opening 16 cm high by 61 cm wide, and a 3 m long 333 μm net with a 30 × 10 cm^2 collecting bag. The net was towed along the surface on the downwind side of the vessel using a spinnaker pole to position the towline outside of the ship's wake. The area sampled was calculated by using the onboard knotmeter, which measures the number of nautical miles traveled over a defined distance, to measure the actual length of sea surface trawled in the 60-min period. The tow length multiplied by the width of the trawl provided the area sampled, allowing particle abundance per square kilometer to be calculated.

The samples were later rinsed in salt water, which floated most of the plastic to the surface for removal. Using a dissecting microscope, plastic was removed from preserved natural material, and then sorted by rinsing through Tyler sieves into 3 size classes: 0.355–0.999 mm, 1.00–4.749 mm, >4.75 mm. Individual pieces of plastic were divided into categories; fragment, foamed polystyrene, line, pellet, film; and then counted.

To understand the surface characteristics and chemical composition of the micro-particles initially sieved from the Great Lakes samples, all particles within the 0.355–0.999 mm size class for each of the 21 samples were examined using scanning electron microscopy (SEM). Samples were spread on double-sided carbon tape, coated with a thin film of evaporated carbon, and then imaged using a Hitachi SU70 field emission SEM operating at 20 keV in backscatter mode. Qualitative elemental composition of particles was confirmed using an Oxford INCA Energy Dispersive X-ray Spectroscopy system (EDS). As SEM analysis showed the development of very healthy biofilms on the surface of collected particles a small fraction of sample 21 was soaked in 2 M hydrochloric acid for a period of 24 h, sieved, rinsed with deionized water and dried prior to SEM analysis in order to image particle surfaces in absence of this biofouling.

3. Results

Of the 21 net tows, all samples except one, sample 13, contained plastic (Fig. 1, Table 1). The initial visual analysis separated natural debris from material suspected to be plastic. The SEM/EDS system was used for microscopic and elemental analysis of particles from all samples <1 mm. Particles >1 mm were more easily identified as plastic, and therefore excluded from SEM/EDS analysis.

Several particles <1 mm were suspected to be paint from the vessel based on the red color and laminate nature. SEM/EDS analyses confirmed that suspected paint fragments were not polymeric and had a nearly identical elemental fingerprint to samples taken from the vessel. It was concluded that these were paint chips from the vessel and they were excluded from plastic particle counts.

SEM/EDS analysis also allowed the determination that many particles initially identified as microplastic were actually aluminum silicates. The aluminum silicate particles were determined to be coal ash and coal fly ash (Fig. 2) based upon a match between our SEM/EDS analysis and similar analyses performed by a commercial ash analysis firm (STS Analytical Testing Laboratory). Of our 21 samples, 8 were found to contain coal/fly ash, with an average contribution of 20% (within the 0.355–1 mm size classification). Our two samples with high particle counts, sample 20 & 21, contained 28% and 27% aluminum silicate, respectively, showing that visual observation alone is insufficient to separate microplastic from other debris.

Natural fibers, aluminum silicate particles and paint fragments were removed from all visually sorted samples. The adjusted microplastic abundance for all samples is given in Table 1. While the samples showed great spatial variability (Fig. 1), with particle counts ranging from ~450 up to over 450,000 per square kilometer, the samples from Lake Erie were consistently the most concentrated as compared to the other two Great Lakes sampled. In fact, Lake Erie samples account for ~90% of all the pelagic plastic debris, with samples 20 and 21 alone containing 85% of all microplastic particles collected in all samples combined. Lake Superior

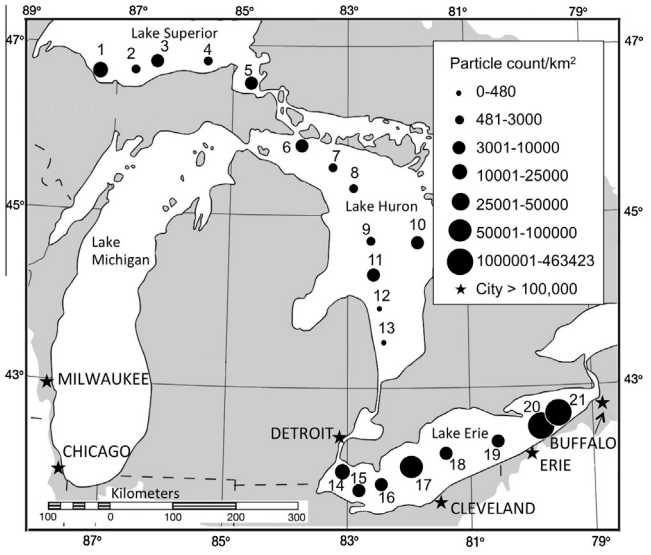

Fig. 1. Distribution of plastic particles by count for 21 samples collected in three of the Laurentian Great Lakes.

[6] http://www.5gyres.org.

Table 1
Count, location and abundance of plastic pollution from 21 stations in three of the Laurentian Great Lakes.

Count, location and abundance of plastic pollution in the Great Lakes					
Sample id.	Latitude	Longitude	Count total	Tow length (km)	Abundance (count/km^2)
Lake Superior					
1	46.5737	−87.3413	15	1.94	12,645
2	46.6872	−86.6649	8	3.70	3541
3	46.7772	−86.4405	3	3.85	1277
4	46.8487	−85.2473	6	3.76	2616
5	46.5860	−84.7222	16	3.82	6875
Lake Huron					
6	45.8682	−83.7218	11	3.80	4750
7	45.6372	−83.3776	3	4.00	1229
8	45.3463	−83.0087	4	3.87	1694
9	44.7287	−82.5399	5	3.70	2213
10	44.7676	−81.9475	15	3.76	6541
11	44.3480	−82.5583	13	3.98	5352
12	43.9240	−82.5130	1	3.59	456
13	43.4134	−82.3994	0	3.93	0
Lake Erie					
14	41.8979	−83.0498	26	3.78	11,282
15	41.7523	−82.9450	9	3.15	4686
16	41.7830	−82.7569	20	3.85	8511
17	41.8953	−82.3409	131	3.76	57,122
18	42.1425	−81.5131	13	3.52	6056
19	42.2441	−80.7501	21	3.78	9112
20	42.3938	−79.9536	1101	3.87	466305
21	42.3000	−80.0259	657	3.83	280947

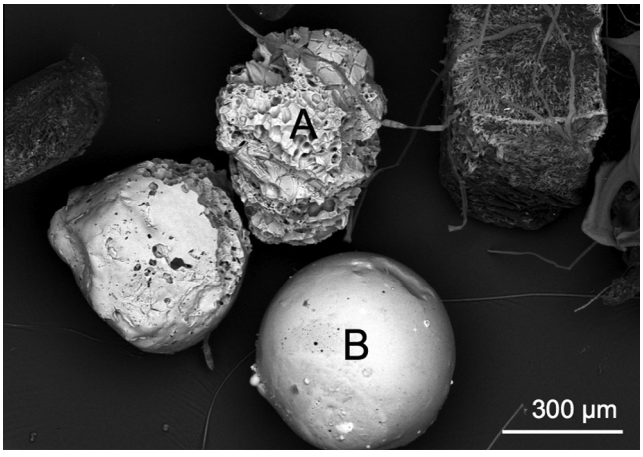

Fig. 2. Coal ash (A) has an irregular surface, whereas coal fly ash (B) does not. Particle B was initially identified as microplastic until SEM/EDS confirmed its inorganic composition.

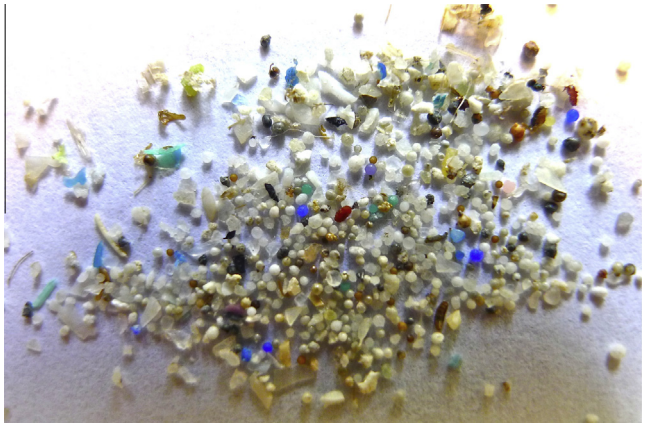

Fig. 3. Color variation among particles <1 mm from Sample 21.

Table 2
Abundance and type of particles in three size classes.

Abundance of plastic particles (count/km^2) by type and size			
	0.355–0.999 mm	1.000–4.749 mm	>4.75 mm
Fragment	247,106.5	123,906.2	11,219.8
Film	3943.5	1332.2	4006.1
Foam	54,340.9	18,208.4	1810.5
Pellet	430,029.8	5614.1	420.9
Line	1328.9	2571.9	449.0
Count/km^2	736,749.6	151,632.9	17,906.3
% Of total	81%	17%	2%

tended to show slightly higher particle counts as compared to Lake Huron.

After adjusting particle counts for all 21 samples from the Great Lakes after SEM/EDS analysis, the average abundance was 43,157 plastic particles/km^2. Table 2 shows the distribution of particles within each of the three size classes, and each of the 5 type categories. Microplastic pellets and fragments were far more abundant than other particle types. The size classes representing particles 0.355–0.999 mm accounted for 81% of the total particle count. Great Lakes sample 20, collected at 42°23.62N, 79°57.21W, contained 1101 plastic particles, or 463,423 particles/km^2, which was the highest count in one 60-min tow and greater than the count of all other samples combined. Several microplastic particles in these samples were green, blue and purple colored spheres, which were suspected to be microbeads from consumer products (Fig. 3).

Two national brands of facial cleansers containing polyethylene microbeads were sieved and analyzed using the SEM/EDS system to evaluate their texture and composition. The microbeads within these consumer products were compared to the multi-colored microplastic spheres in the samples, and found to be of similar shape, size, color and elemental composition (Fig. 4).

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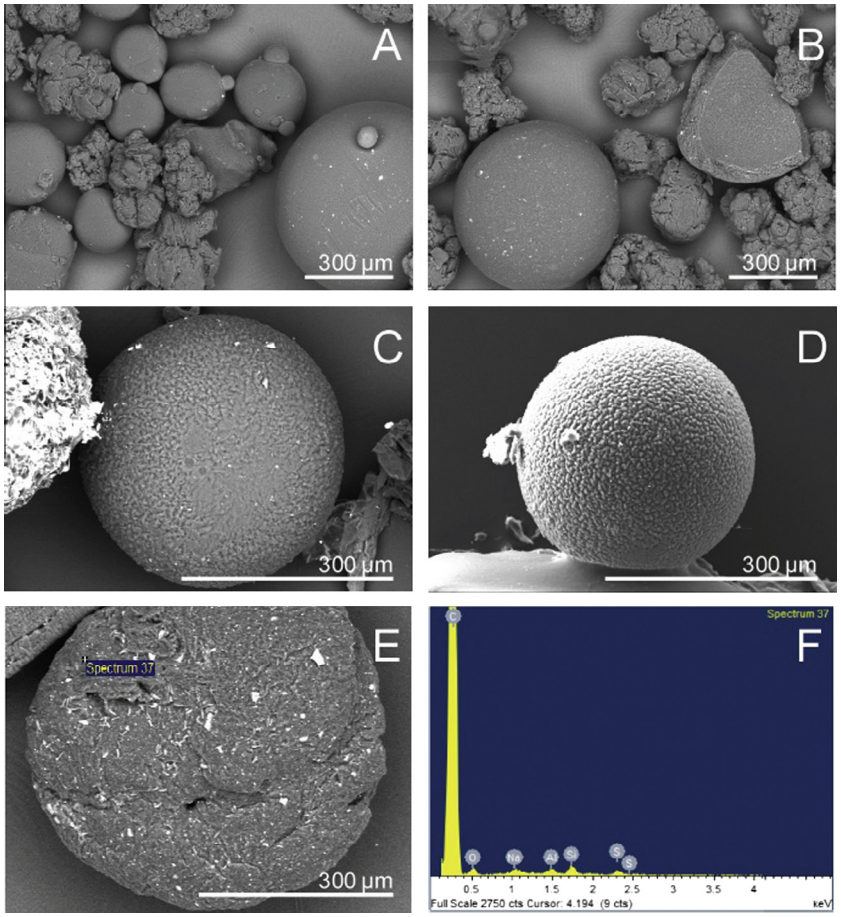

Fig. 4. (A) SEM image of product 1 containing polyethylene microbeads. (B) Polyethylene microbeads in product 2. (C & D) SEM image of spherical fragment from GL 21 after HCl wash. (E) SEM image of blue spherical fragment from GL 21. (F) Elemental analysis of fragment E showing it to be polymeric material.

4. Discussion

The results of this study posed several questions about the source of microdebris, including the identity of microplastic particles. Many coal and fly ash particles were found. In the 8 states that border the Great Lakes, there are 144 coal-burning power plants (Stamper et al., 2012), which may release aluminum silicates in the form of coal ash or fly ash into waterways through wastewater discharge or aeolian transport. These inorganic microdebris were removed from the samples, leaving abundant microplastic particles with physical characteristics similar to microbeads used in two primary commercial applications: sandblasting media and abrasives in consumer products.

Sandblasting media using polymeric materials include acrylic, with a density of 1.19 g/cm^3, polystyrene (1.05 g/cm^3), melamine (1.51 g/cm^3), thermoset polyester polymer (1.5 g/cm^3), poly allyl diglycol carbonate (1.31 g/cm^3), amino thermoset plastic (1.47–1.52 g/cm^3) and urea (1.50 g/cm^3). All of these materials would be negatively buoyant in freshwater, and therefore are not likely to appear within samples obtained in the Great Lakes.

Multi-colored spherical particles in the size class <1 mm (Fig. 3) may be linked to consumer products. Some facial cleansers, and other personal care products, contain spherical microbeads labeled on the product as polyethylene (0.91–0.96 g/cm^3) or polypropylene (0.91 g/cm^3), which would float in freshwater systems. Once used by the consumer, the plastic microbeads may be washed down the drain, but few, if any, wastewater treatment facilities capture all floating, non-biodegradable particulate of 0.5 mm size or smaller. Sewage sludge, which may contain microbeads, is often used as fertilizer in agriculture and public lands (Saruhan et al., 2010). Also, during high rain events some municipalities, which have combined sewer systems, may experience combined sewage overflow (CSO) events allowing raw sewage to enter local waterways untreated (EPA, 2007). Hence, there are multiple point sources where microbeads may enter the marine environment.

There are a number of factors that may contribute to the large spatial variability of plastic pollution in our samples. Of the 3 lakes studied, Lake Erie is the most populated, which might account for the consistently high counts obtained for each of the 8 samples obtained within this lake as compared to the others. While Lake Superior is the least populated of the 3 lakes, all 5 of our samples within this lake were closer to the shorelines (and thereby closer to the source of pollution) than was the case for Lake Huron, for example. This may explain why the average counts for Lake Superior samples were greater than those for Lake Huron.

Samples 20 and 21 were an anomaly in terms of relative abundance compared to all other samples. The abundance of microdebris, including both coal ash and microplastic particles, may be a result of the convergence of currents in Lake Erie. Annual mean current modeling suggest that currents in Lake Erie are pushed southward along the shoreline (Beletsky et al., 1999). These two samples were collected in the area of converging currents, are in close proximity to several coal burning power plants (Stamper et al., 2012) and are directly downstream from the cities of Detroit, MI, Cleveland, OH and Erie, PA, (Fig. 1).

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5. Conclusion

This study aimed to investigate the presence of plastic pollution in the Laurentian Great Lakes ecosystem. In July 2012 a total of 21 samples were collected in three of the five Great Lakes, with overall counts varying from 0 to over 450,000 plastic particles per square kilometer yielding an average count density of 43,157 ± 115,519 particles/km^2.

SEM/EDS analyses of all particles <1 mm differentiated microplastics, including multi-colored plastic spheres, from other materials such as coal ash. Based on dense urban populations adjacent to the lakes that employ combined sewage overflow, and the convergence of lake currents near our sample sites, we believe the microplastic spheres may be microbeads used in consumer product applications, such as those used in facial cleansers. Though sandblasting media may release microplastic particles to the environment, their negative buoyancy in freshwater likely eliminates them as a drifting pollutant. Our study supports the work of Fendall and Sewell (2009), which suggested that the average consumer may be directly releasing microplastics of a size suitable for ingestion by marine organisms without having degraded to become that size. Microbeads are microplastic by design and have similar consequences in the marine environment.

The presence of significant amounts of coal ash and coal fly ash in our samples from the Great Lakes confirms the importance to conduct elemental analysis (SEM/EDS) or chemical analysis (FT-IR) of debris to avoid misidentification. Understanding the type and abundance of microplastics in near shore environments will assist efforts to identify and mitigate sources of plastic marine pollution.

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