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Microplastic pollution in St. Lawrence River sediments

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Abstract: Although widely detected in marine ecosystems, microplastic pollution has only recently been documented in freshwater environments, almost exclusively in surface waters. Here, we report microplastics (polyethylene microbeads, 0.40–2.16 mm diameter) in the sediments of the St. Lawrence River. We sampled 10 freshwater sites along a 320 km section from Lake St. Francis to Québec City by passing sediment collected from a benthic grab through a 500 μm sieve. Microbeads were discovered throughout this section, and their abundances varied by four orders of magnitude across sites. Median and mean (±1 SE) densities across sites were 52 microbeads·m^{-2} and 13 832 (±13 677) microbeads·m^{-2}, respectively. The highest site density was 1.4×10^5 microbeads·m^{-2} (or 10^3 microbeads·L^{-1}), which is similar in magnitude to microplastic concentrations found in the world's most contaminated marine sediments. Mean diameter of microbeads was smaller at sites receiving municipal or industrial effluent (0.70 ± 0.01 mm) than at non-effluent sites (0.98 ± 0.01 mm), perhaps suggesting differential origins. Given the prevalence and locally high densities of microplastics in St. Lawrence River sediments, their ingestion by benthivorous fishes and macroinvertebrates warrants investigation.

Résumé : Même si elle est largement observée dans les écosystèmes marins, ce n'est que récemment que la pollution microplastique a été documentée dans des milieux d'eau douce, et ce, presque exclusivement dans des eaux de surface. Nous faisons état de la présence de microplastiques (des microbilles de polyéthylène de 0,40 à 2,16 mm de diamètre) dans les sédiments du fleuve Saint-Laurent. Nous avons échantillonné 10 sites d'eau douce le long d'un tronçon de 320 km allant du lac Saint-François à Québec, en faisant passer des sédiments prélevés à la benne benthique par un tamis de 500 μm. Des microbilles ont été détectées tout au long du tronçon, leur abondance variant sur quatre ordres de grandeur selon le site. Les densités médianes et moyennes (±1 erreur-type) pour tous les sites étaient de 52 microbilles·m^{-2} et 13 832 (±13 677) microbilles·m^{-2}, respectivement. La densité la plus élevée observée en un site était de $1,4 \times 10^5$ microbilles·m^{-2} (ou 10^3 microbilles·L^{-1}), ce qui est semblable aux concentrations de microplastique observées dans les sédiments marins les plus contaminés du monde. Le diamètre moyen des microbilles était plus faible dans les sites qui reçoivent des effluents municipaux ou industriels (0,70 ± 0,01 mm) que dans les autres sites (0,98 ± 0,01 mm), indiquant éventuellement différentes origines. Étant donné la prévalence et les densités localement élevées de microplastiques dans les sédiments du fleuve Saint-Laurent, il serait pertinent d'examiner leur ingestion par les poissons et macroinvertébrés benthivores. [Traduit par la Rédaction]

Introduction

The contamination of marine ecosystems by synthetic polymers (plastics) has been recognized since the 1970s (Carpenter and Smith 1972; Cole et al. 2011; Lusher et al. 2013; Van Cauwenberghe et al. 2013; Ivar do Sul and Costa 2014). Increasingly prevalent in these environments is microplastic pollution — small particles (<5 mm) that are either manufactured as granules (e.g., in abrasive products such as cosmetics and cleansers) or originate from degraded plastic debris (Fendall and Sewell 2009; Barnes et al. 2009). The ecological effects of this pollution are poorly understood but are starting to become apparent. In marine systems, microplastics occur in the water column (Cole et al. 2011) and in nearshore and deep-sea sediments (Vianello et al. 2013; Van Cauwenberghe et al. 2013), where they may be ingested by benthic invertebrates (Browne et al. 2008; Graham and Thompson 2009; Murray and Cowie 2011; Goldstein and Goodwin 2013) and demersal fishes (Lusher et al. 2013). Once consumed, they can be passed on to higher trophic levels (Farrell and Nelson 2013; Setälä et al. 2014). The accumulation of microplastics in the digestive tract may satiate the consumer and result in lower energy acquisition (Wright et al. 2013*a*). In addition, persistent and highly toxic organic contaminants readily adsorb to the surface of microplastics (Rios et al. 2007) and can be transferred to sediments (Teuten et al. 2007) and consumers (Rochman et al. 2013).

In recent years, microplastics have been discovered abundant in the surface waters and along the shorelines of the Laurentian Great Lakes (Eriksen et al. 2013; Zbyszewski et al. 2014), one of the few freshwater systems in which they have been reported (see also Faure et al. 2012; Imhof et al. 2013; Sanchez et al. 2014; Lechner et al. 2014). Trawl nets have collected hundreds of microplastic particles in the surface waters of Lakes Superior, Huron, and Erie (Eriksen et al. 2013). The physical and chemical characteristics of many of these particles are similar to those of microbeads from household consumer products, which are apparently not degraded or completely removed by wastewater treatment facilities. No studies to date have addressed the presence of microplastics in North American freshwater sediments. Floating microbeads in the Great Lakes, or those originating from municipalities along the St. Lawrence River, could be flushed downstream and be either deposited in the river's sediments or carried into the estuary. The rapid formation of microfilm on these particles and their biologically

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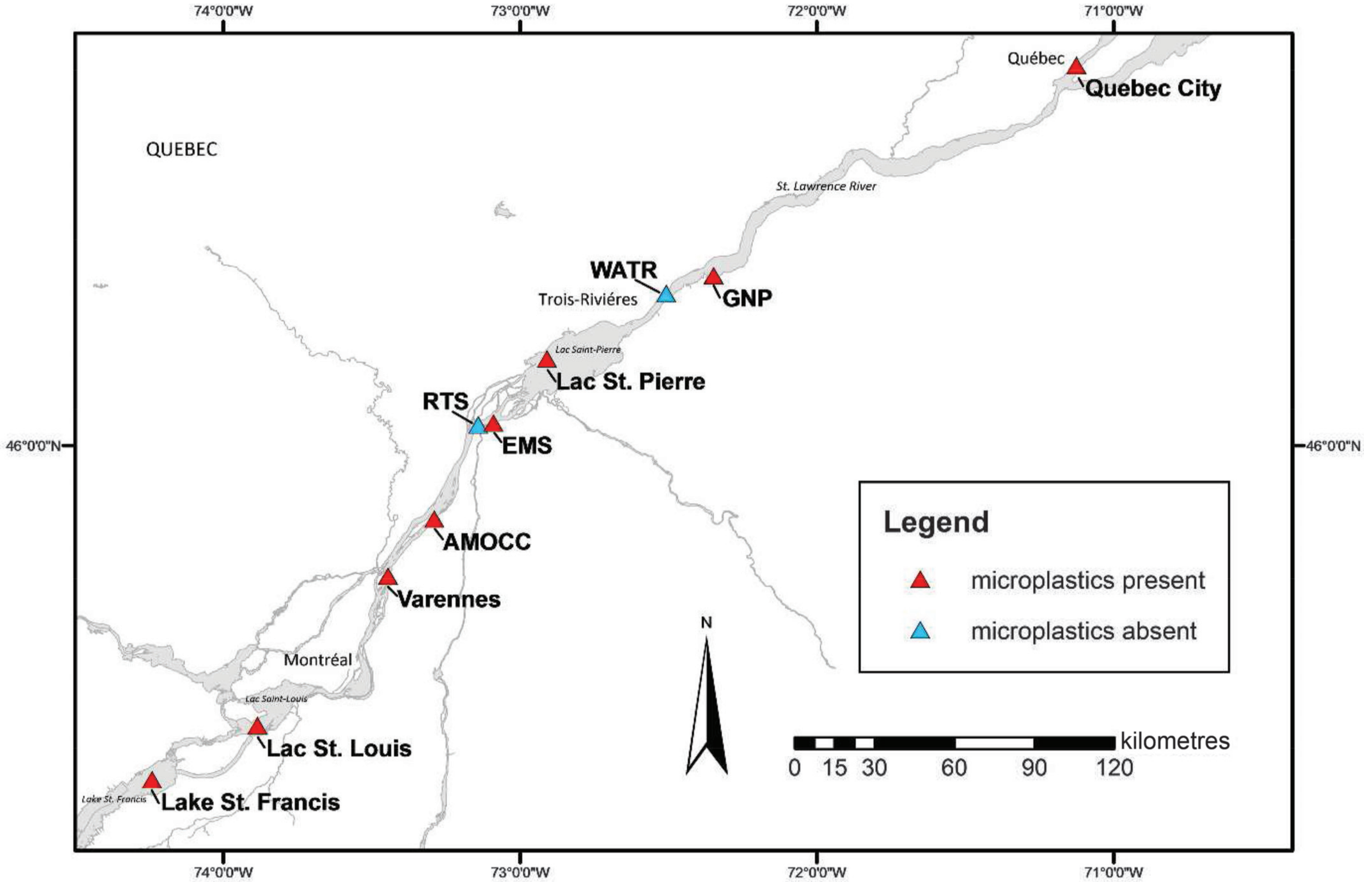
Fig. 1. Sampled sites in the St. Lawrence River.



enhanced aggregation (Van Cauwenberghe et al. 2013) can cause them to become negatively buoyant and sink into sediments, where they may accumulate owing to very slow rates of degradation. They could also be readily ingested by fish (Sanchez et al. 2014) and perhaps freshwater invertebrates, which are thus exposed to toxic contaminants leaching from their surfaces (Rochman et al. 2013). Here, we document the spatial extent and density of microplastic pollution in the sediments of the St. Lawrence River.

Methods

Sediment samples from a total of 10 sites, each with a varying number of subsites, were collected from the St. Lawrence River. During September 2013, we sampled five sites along a 320 km freshwater section of the river: Lake St. Francis, Lac Saint-Louis, Varennes, Lac Saint-Pierre, and Québec City (Fig. 1). Each site, except Québec City, comprised three subsites along a 5 km transect from which two samples of sediment were collected using a petite Ponar grab (225 cm^2 area), for a total of six samples per site. The Québec City site included four subsites where a single Peterson grab (930 cm^2 area) was used to collect sediment. In 2010, a Peterson grab was used to sample multiple subsites from locations downstream of municipal and industrial effluents; these locations are coded AMOCC, EMS, RTS, and WATR. Finally, in June 2013, two petite Ponar grabs were taken at three subsites within the effluent canal of the Gentilly-2 Nuclear Power Plant (GNP). All petite Ponar grabs were taken by a single researcher, who sampled a near constant sediment depth of ~10 cm. All Peterson grabs were taken by another researcher, who sampled sediment depths varying from 10 to 15 cm. Each sediment sample was sieved through 500 μm mesh and preserved in ethanol, prior to inspection.

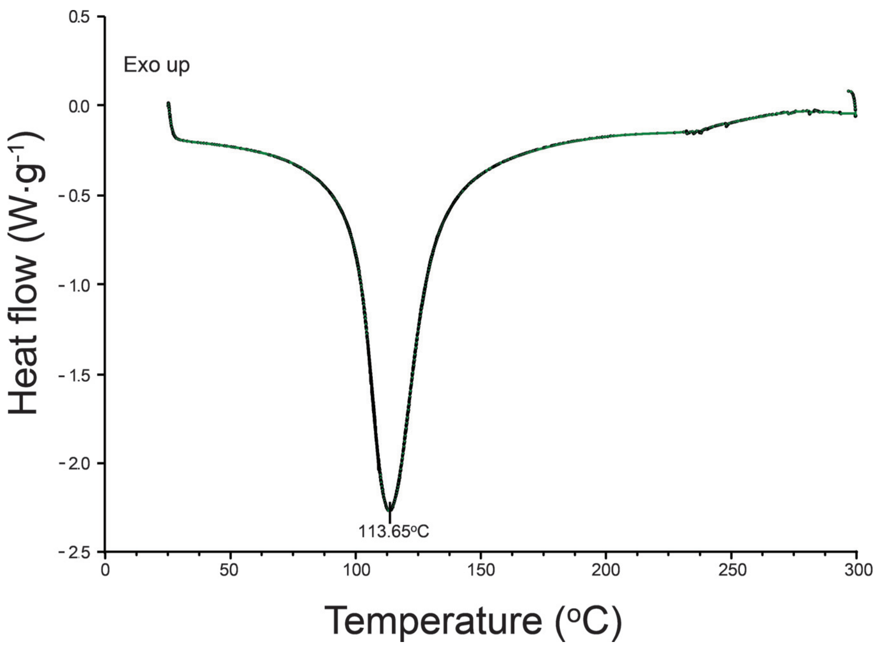
Under a dissecting microscope, granular microplastic particles (microbeads) were identified visually based on their colour, texture, and (in >99% of cases) spherical shape. The microbeads were separated manually from the entire volume of sediment, then enumerated and photographed. All sediment samples were processed by the same researcher, who later inspected random samples of separated material to determine whether any microplastics were missed during processing; none were recovered during these checks. Diameters of the microbeads (sample n = 208) were measured from the photographs using ImageJ (Rasband 1997). Mean diameters of microbeads found in non-effluent and effluent sites were compared statistically. To determine the chemical composition of the microbeads, their melting temperature and crystallization were analysed using differential scanning calorimetry. Numerical densities (m^{-2}) and concentrations (L^{-1}) per site were estimated from the area and volume, respectively, of the benthic grab.

Results

Microbeads retained by a 500 μm sieve were found at 8 of 10 sites along the 320 km section of the St. Lawrence River (Fig. 2). The median and mean numerical densities of microbeads across all sites were 52 and 13 759 ± 13 685 (SE) m^{-2}, respectively (Table 1). The highest mean site density (136 926 ± 83 947 m^{-2}, or 1369 L^{-1}) occurred at GNP, where a maximum local (subsite) density of 398 000 m^{-2} (3980 L^{-1}) was recorded. Microbeads occurred in a variety of colours and sizes (Fig. 2), similar to some of those collected in the surface waters of the Great Lakes (Eriksen et al. 2013). Their melting point was 113.7 °C, suggesting a polyethylene composition (Fig. 3). Their diameters ranged from 0.4 to 2.16 mm, with a mean of 0.76 ± 0.02 mm and a skewed size–frequency distribu-

Fig. 2. Sample of microbeads found in St. Lawrence River sediments.

Fig. 3. Differential scanning calorimetry thermal response plot for microbead sample.



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tion that indicated three modes (Fig. 4). Microbead size varied across sites such that those at sites receiving effluent were of significantly smaller diameter (mean = 0.70 ± 0.01 mm) than those at non-effluent sites (mean = 0.98 ± 0.06 mm) (Mann–Whitney test, $p < 0.001$).

Discussion

Our results suggest that microplastics are ubiquitous and locally abundant in the sediments of the St. Lawrence River. Their patchy distribution and abundance, including their apparent absence from two sites, might be explained by environmental factors that affect sediment deposition (e.g., water currents, shoreline topography); a marine study (Vianello et al. 2013) found that mi-

Table 1. Microbead density at sampling sites (*n* represents the number of subsites) in the St. Lawrence River.

Site	*n*	Density ± SE (m^{-2})
Lake St. Francis	3	57±38
Lac Saint-Louis	3	86±40
Varennes	3	7±7
Lac Saint-Pierre	3	43±29
AMOCC*	4	185±63
EMS*	4	46±21
RTS*	3	0
WATR*	3	0
GNP*	3	136 926±83 947
Québec City	4	243±122

*Sites receiving municipal or industrial effluents.

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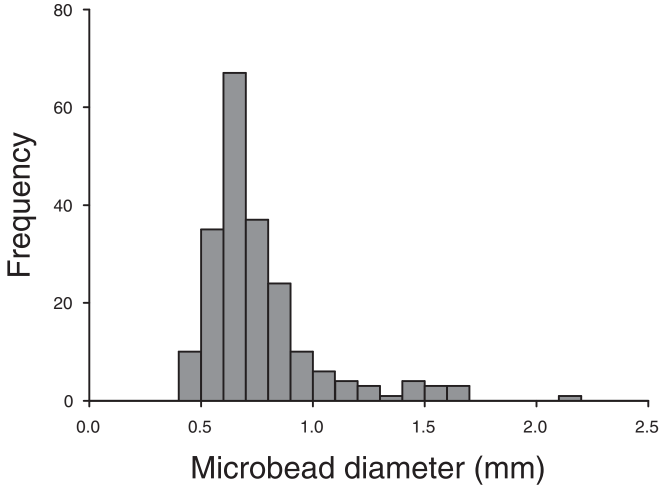
Fig. 4. Size–frequency histogram of microbeads obtained from St. Lawrence River sediments.



croplastics, like fine sediments, tend to concentrate in low-energy sites. The two sites where microplastics were undetected are located near industrial effluents; one (RTS) is near a metallurgical plant, whereas the other (WATR) is near a pulp-and-paper mill. The latter had the coarsest sediments (gravel and cobble) among all sites, indicating that it was not a depositional area.

Differences in microbead size suggest that those from effluent sites generally originate from a distinct source. Most (99.9%) of the microbeads found in our study were <2 mm in diameter. The size, shape, and chemical composition of these microbeads (Figs. 2 and 3) are similar to ones found in the Great Lakes (Eriksen et al. 2013) and closely resemble those used in consumer products (e.g., Fendall and Sewell 2009).

The buoyancy of some microplastics has led most scientists to monitor their presence by sampling surface waters and beach shore sediments (e.g., Hidalgo-Ruz et al. 2012; Zbyszewski et al. 2014). A recent survey quantified microplastic litter drifting through the Danube River to the Black Sea at a rate of 4 t·day^{-1} (Lechner et al. 2014). Our study demonstrates that freshwater sediments can act as a sink for these pollutants, which can reach abundances of the same order of magnitude (10^5 m^{-2} and 10^3 L^{-1}) as those found in the most contaminated marine sediments (Van Cauwenberghe et al. 2013; Wright et al. 2013*b*), in spite of the greater range of plastics considered in the latter cases. The densities we have recorded may substantively underestimate actual abundances of microplastics in sediments, given that our sampling regime excluded a smaller size fraction (<500 μm) that has been observed in surface waters of the Great Lakes (Eriksen et al. 2013) and in marine sediments (Van Cauwenberghe et al. 2013), as well as larger fragments (>2 mm) and fibers that have been found along the beaches of lakes (Imhof et al. 2013; Zbyszewski et al. 2014). Moreover, our specimen sorting was visual and more readily identified spherical particles as well as coloured or textured granules and thus potentially overlooked irregular fragmented microplastic particles, such as those used in some cosmetics and air-blasting media (Gregory 1996; Fendall and Sewell 2009).

We suspect that microplastics are common in the sediments of other large lakes and rivers situated in heavily populated watersheds. Their prevalence in the St. Lawrence River raises the likelihood of ingestion by detritivorous and suspension feeding invertebrates and benthivorous fishes. Indeed, in a diet study of an invasive benthic fish, round goby (*Neogobius melanostomus*), in the St. Lawrence River in 2008, microbeads similar in shape and size to the ones found in our study were discovered in round goby digestive tracts (R. Kipp and A. Ricciardi, personal observation), but were not quantified. Consumption of microplastics by freshwater animals has hardly been explored. In the only published study on freshwater fish ingestion of microplastics, Sanchez et al. (2014) found polymer fibers and pellets in the digestive tracts of another benthic species, gudgeon (*Gobio gobio*), in French rivers. The extent to which microplastics have become incorporated into the St. Lawrence River food web — and the consequences for biotic communities — remain to be determined.

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