Marine Pollution Bulletin 110 (2016) 383–395

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Sources and sinks of microplastics in Canadian Lake Ontario nearshore, tributary and beach sediments

Anika Ballent [a,*], Patricia L. Corcoran [a], Odile Madden [b], Paul A. Helm [c], Fred J. Longstaffe [a]

[a] Department of Earth Sciences, University of Western Ontario, 1151 Richmond St. N., London, ON, N6A 5B7, Canada
[b] Museum Conservation Institute, Smithsonian Institution, 4210 Silver Hill Rd., Suitland, MD, 20746, USA
[c] Environmental Monitoring and Reporting Branch, Ontario Ministry of the Environment and Climate Change, 125 Resources Rd., Toronto, ON, M9P 3V6, Canada

ARTICLE INFO

Article history:
Received 31 March 2016
Received in revised form 8 June 2016
Accepted 9 June 2016
Available online 21 June 2016

Keywords:
Microplastics
Lake Ontario
Sediments
Raman spectroscopy
Nearshore
Watershed

ABSTRACT

Microplastics contamination of Lake Ontario sediments is investigated with the aim of identifying distribution patterns and hotspots in nearshore, tributary and beach depositional environments. Microplastics are concentrated in nearshore sediments in the vicinity of urban and industrial regions. In Humber Bay and Toronto Harbour microplastic concentrations were consistently >500 particles per kg dry sediment. Maximum concentrations of ~28,000 particles per kg dry sediment were determined in Etobicoke Creek. The microplastic particles were primarily fibres and fragments <2 mm in size. Both low- and high-density plastics were identified using Raman spectroscopy. We provide a baseline for future monitoring and discuss potential sources of microplastics in terms of how and where to implement preventative measures to reduce the contaminant influx. Although the impacts of microplastics contamination on ecosystem health and functioning is uncertain, understanding, monitoring and preventing further microplastics contamination in Lake Ontario and the other Great Lakes is crucial.

1. Introduction

Studies concerning plastics contamination of marine environments began in the 1970s (e.g. Carpenter and Smith, 1972; Colton et al., 1974), and since that time, investigations have shown that plastic waste is consistently found in aquatic environments including beaches, ocean surface waters, deep-sea sediments, freshwater lakes, and tributaries (e.g. Eriksen et al., 2013; Van Cauwenberghe et al., 2013; Vianello et al., 2013; Cózar et al., 2014; Turra et al., 2014; Eerkes-Medrano et al., 2015). Contamination of aquatic environments with plastics has become a global issue as a result of low recycling rates, designs that do not include the post-consumer stage of the product, and lack of policies that support a circular plastics economy (Neufeld et al., 2016).

Microplastics, defined as plastic particles <5 mm long (NOAA, 2015), are either manufactured for use in applications such as cosmetics, personal care products, industrial abrasion processes and synthetic fabrics (Fendall and Sewell, 2009; Eriksen et al., 2013; Sundt et al., 2014), or are generated by the degradation of larger plastic products (Carpenter and Smith, 1972; Sundt et al., 2014). In a recent study, microbeads, many of which were comparable to particles isolated from cosmetic products, comprised an estimated 58% of microplastics <1 mm in size collected from the surface waters of the Great Lakes (Eriksen et al., 2013). Several countries, including Canada and the United States, have since begun the process of banning the sale of cosmetic products containing microplastics. Polyethylene (PE) and polypropylene (PP), often used in the production of cosmetic microplastics, have densities less than that of fresh water, but have nonetheless been regularly identified in submerged sediments (Claessens et al., 2011; Vianello et al., 2013; Corcoran et al., 2015). The study of microplastics in sediment is therefore needed for a comprehensive understanding of microplastics contamination in the Laurentian Great Lakes.

Microplastics pollution has been reported from Great Lakes surface waters (Eriksen et al., 2013), along shorelines (Zbyszewski and Corcoran, 2011; Zbyszewski et al., 2014; Corcoran et al., 2015) and in offshore lake bottom sediments (Corcoran et al., 2015), but its presence in subsurface sediments of nearshore regions and tributaries is still largely unknown (Driedger et al., 2015). Allan et al. (2013) modeled current environmental stressors affecting the Great Lakes and found that cumulative stress levels were greatest in nearshore regions and generally decreased with distance from the shore. Only one investigation concerning microplastics pollution in Lake Ontario sediments has been published to date (Corcoran et al., 2015), despite it being the terminal lake within the Great Lakes system. In addition, the lake is surrounded by highly urbanized and industrialized regions, particularly along the northern shore, which have been associated with the accumulation of plastic debris (e.g. Barnes et al., 2009; Turra et al., 2014). We herein provide a regional investigation of the abundance and depositional patterns of microplastics in nearshore, tributary and beach

---

[*] Corresponding author.
E-mail address: 4anikab@gmail.com (A. Ballent).

http://dx.doi.org/10.1016/j.marpolbul.2016.06.037
0025-326X/

sediments along the Canadian shoreline of Lake Ontario in an effort to provide: (i) a baseline for future monitoring, (ii) a means to assess potential sources of microplastics to the lake, and (iii) a distribution map of current microplastics hotspots.

Microplastics in benthic ecosystems pose an environmental threat primarily because organisms that feed on the benthic community may potentially ingest microplastics. Littoral and profundal fish species in large temperate lakes have diets that consist primarily of benthic organisms, and in Lake Ontario ~92% of fish and ~96% of invertebrate species are found in littoral habitats (Vadeboncoeur et al., 2011). The majority of aquatic species in Lake Ontario are closely connected to nearshore benthic habitats, and microplastics contamination of these sediments may be directly affecting the health of the lake ecosystem at many trophic levels. Although plastics are not classified as hazardous waste in Canada, certain plastic products, such as polycarbonate CD-ROM discs and polyurethane foams commonly used in furniture, are manufactured from hazardous derivatives (Lithner et al., 2009). Additives such as polybrominated diphenyl ethers (PBDEs; e.g. flame retardants) (Lithner et al., 2011; Rochman et al., 2014) and plasticizers such as Bisphenol-A are also often included to change the physical properties of the plastics (Oehlmann et al., 2009). Plasticizers have been shown to have negative impacts on the hormonal systems of invertebrates, fish and amphibians (Oehlmann et al., 2009). Conclusive evidence for the transfer of associated hazardous compounds from plastics to organisms is lacking, but several studies have suggested correlations between plastics ingestion and compromised physiological function (e.g. Teuten et al., 2009; Wright et al., 2013; Syberg et al., 2015). An additional threat of microplastics is their role as colonization surface habitats for bacteria or other organisms, which may lead to the invasive transport of microbial communities (e.g. Ye and Andrady, 1991; Zettler et al., 2013; Harrison et al., 2014; McCormick et al., 2014; Nauendorf et al., 2016).

A comprehensive overview provided by Eerkes-Medrano et al. (2015) highlights our limited understanding of microplastics contamination in freshwater systems. Rivers and urban tributaries, however, have been shown to be major transport pathways for microplastics and macroplastics, plastics >5 mm (Moore et al., 2011; Gasperi et al., 2014; Lechner et al., 2014; Rech et al., 2014; Zhao et al., 2014; Corcoran et al., 2015; Naidoo et al., 2015). Whereas buoyant materials are transported on surface waters (Gasperi et al., 2014), non-buoyant materials are transported along the tributary bed (Moore et al., 2011; Morritt et al., 2014). Microplastic debris loads can be introduced into tributaries via non-point spill and litter sources as well as point sources such as effluent pipes (Lechner and Ramler, 2015), storm water drainage outlets (Armitage & Rooseboom 2000) and possibly wastewater treatment plants, particularly during combined sewage overflow and bypass events during heavy precipitation conditions (MacDonald and Podolsky, 2009). Rech et al. (2014) and Corcoran et al. (2015) showed that macroplastic and microplastic debris loads carried by rivers are also deposited along river banks, suggesting that rivers are both depositional and erosional zones for anthropogenic debris.

2. Setting and methods

2.1. Setting

Lake Ontario drains an area of slightly >64000 km^2 and is the terminal lake in the Laurentian Great Lakes chain (Fig. 1). Prevailing wind patterns in the Toronto region from November to February are mainly NW to WSW, and gradually shift to ENE-dominated from March to October. The western end and the northwestern shore of the lake are characterized by several urban and industrial regions, including the cities of Hamilton, Mississauga and Toronto, with populations of 0.52, 0.71 and 2.62 million, respectively. Plastics manufacturing in Canada is concentrated in Southern Ontario (Statistics Canada, 2012). According to a 2014 statistical report of the Canadian Chemical Industry (CIAC), production of synthetic resins, fibres and rubbers included PE, ethylene vinyl acetate, polystyrene (PS), polyvinyl chloride (PVC), polyacrylamides, polyethylene terephthalate (PET), nylons, latex emulsions, polyesters, silicones and butyl and halobutly rubbers (CIAC, 2014, p. 34). High-density resins comprised 16% and PE comprised 80% of Canadian synthetic resin/rubber exports by weight in 2013 (CIAC, 2014, p. 35). In total, ~3500 kt of PE were produced in 2013 (CIAC, 2014, p. 34).

2.2. Sample collection

Nearshore, tributary and beach sediments were sampled using a combination of sediment trap, core and grab sampling techniques in order to obtain as many data points as possible. The original objective was to collect all nearshore samples using a Glew gravity corer, but this method proved to be especially challenging as a result of the high wave action in Lake Ontario. The Ontario Ministry of the Environment and Climate Change (MOECC) donated Shipek grab samples, in addition to passive sediment trap samples that they had collected from Lake Ontario (Nearshore Index and Reference sites, Great Lakes Nearshore Monitoring Program). Tributary sediment was best sampled using a petite ponar grab that could be lowered from a standing position. Beach sediment was sampled using a split spoon corer, as it was originally thought that depth below the surface could be related to microplastics abundance. However, given the highly variable hydrodynamic conditions that take place on beaches, we have chosen to represent all sediment depths at each beach as a whole. The use of various sampling methods enabled a greater spatial resolution, but temporal (annual and seasonal) constraints were not possible. Sample names, dates, sampling instruments, depositional environments, locations, and water depths are detailed in Table 1.

A total of 33 nearshore samples were collected (Table 1; Fig. 1). Five nearshore sediment samples were collected using a Glew gravity corer in August 2014. The PVC cores measured 6.5 cm in diameter, and ranged between 6 and 15 cm thick. Immediately after recovery, the gravity cores were extruded into 1 cm intervals ($N \leq 15$) and stored in sealed PE bags. Twenty-five samples were collected by the MOECC from the Canadian shoreline of Lake Ontario and the proximal St. Lawrence River in August 2012 and July 2014 using a Shipek grab sampler with a square opening of 20 cm and a half-cylindrical cup with a radius of 10 cm (Wildco, Yulee, FL). Three replicate grab samples were collected from each station, homogenized in a metal tray and transferred into 0.5 L PET collection bottles. Three additional nearshore samples were collected by the MOECC from sediment traps in November 2014. The traps comprised an array of four acrylic cylinders, secured at approximately 2 m above the lake bed, and were allowed to collect sediment for 6 months.

Tributary sediment samples from Red Hill Creek, Etobicoke Creek, Humber River and Don River (Fig. 1) were obtained with a 16 × 14.5 cm hand-held, stainless steel Petite Ponar sediment grab (Wildco, Yulee, FL). Sample locations were constrained foremost by accessibility and second by the presence of sediment depositional zones. At each of seven sample locations, 2 grab sample replicates were combined in a metal tray and were spooned into 0.5 L PET collection bottles.

Sediment was also sampled from five east and south facing beaches along the north-western shore of Lake Ontario in June 2015: Beachway Park, Bronte Beach, Marie Curtis Park, Sunnyside Beach and Woodbine Beach (Fig. 1). Much of the northern shore of Lake Ontario has been built up with large boulders or is inaccessible due to privatization of lands, which limited sample sites to public sandy beaches. Using a stainless steel split spoon corer with a height of 30 cm, two cores were collected from each beach at approximately 2 m and 6 m from the waterline, representing the proximal and distal foreshore, respectively. The foreshore sediments are regularly submerged with seasonal changes in water level as well as during storm surges. The corer was equipped with an inner, segmented PVC core, each segment measuring 10 cm long. Upon opening the core, each segment was covered with a PE cap. All proximal foreshore sites, except at Marie Curtis Beach, were