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Comparison of the distribution and degradation of plastic debris along shorelines of the Great Lakes, North America

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ABSTRACT

The distribution patterns, compositions and textures of plastic debris along the Lake Erie and St. Clair shorelines were studied in order to determine the roles of potential source locations, surface currents, and shoreline types in the accumulation of plastic litter. The results were compared with those previously determined from Lake Huron, where abundant plastic pellets characterize the southeastern shoreline. Lake Erie and St. Clair shorelines contained some pellets, but were mainly characterized by plastic fragments and intact products, respectively. The potential sources for the pellets include spillage within factories or during transport and off-loading; whereas intact products were derived from urban waste. Once entering the lake environment, low density floating polymers such as polyethylene and polypropylene were degraded by UVB radiation at either the water surface or once deposited on shorelines. Mechanical degradation by wave action and/or sand abrasion fragmented intact products into cm-size particles. Certain textures identified on the surfaces of plastic particles could be related to the nature of the depositional environment. Plastics sampled from infrequently visited muddy, organic-rich shorelines were characterized by more adhering particles and less mechanical pits than those from sandy shorelines. In terms of relative distribution, the Lake St. Clair shoreline contained the least amount of plastic debris of the three lakes. This is a function of the breakwaters and retaining walls built along Lake St. Clair, which replace natural sandy or muddy sinks for floating polymers. This study represents the first detailed record of plastics distribution along multiple, but related fresh water shorelines.

Introduction

Plastic debris in the environment poses a significant threat because of its resistivity to photo-oxidative, thermal, mechanical and biological processes (Andrady, 2003; Shah et al., 2008). Although overlooked for many years, the amount of plastic debris accumulating in the environment has been steadily increasing (Goldstein et al., 2012; Ryan and Moloney, 1993; Thompson et al., 2004) as a result of the material's durability, lightweight nature, and low cost of production (Laist, 1987). Once discarded on land, plastic debris makes its way to water bodies that act as sinks for low density litter (Moore, 2008). Topography, wind and water currents, and proximity to pollution sources control the amount and types of plastics along shorelines; whereas, degradation processes determine how long plastic debris remains on beaches (Barnes et al., 2009; Corcoran et al., 2009; Derraik, 2002; Storrier et al., 2007). Monitoring the amount of plastic debris entering the environment is most readily accomplished by examining stranded litter on beaches (Coe and Rogers, 1997). Generally, plastic beach litter is composed of manufactured products, either whole or broken down, and the plastic pellets used to manufacture these products (Goldberg, 1997).

Plastics pollution has considerable impact on marine ecosystems. Entanglement, one of the most visible impacts of plastic debris, affects 260 species of marine organisms (STAP, 2011). Once entangled in items such as ropes, nets, and packing loops, most animals have difficulty escaping which may lead to strangulation, drowning or starvation (Boren et al., 2006; Gregory, 2009; Mattlin and Cawthorn, 1987). Plastics ingestion is more frequent than entanglement and can result in death by starvation due to blockage of digestive tracts and reduction of reproductive capacity (Eriksson and Burton, 2003; Laist, 1987; Mascarenhas et al., 2004). Plastics have also been shown to sorb micropollutants from the surrounding water (Endo et al., 2005; Engler, 2012; Mato et al., 2001; Rios et al., 2010) which could potentially bioaccumulate in organisms ingesting the plastic (Teuten et al., 2009). Hirai et al. (2011) analyzed the concentrations of organic micropollutants in beach and open ocean plastic debris and found that nonylphenol, bisphenol A, and polybrominated diphenyl ethers (PBDEs) were additives that could prove hazardous if ingested. Of additional concern are microplastics which are up to 5 mm in diameter (Arthur et al., 2009) and enter the environment from cleansers, cosmetic preparations and airblast cleaning media (Derraik, 2002; Fendall and Sewell, 2009). The minute size of the micro-plastics makes them of

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immediate concern as they are small enough to be ingested by zooplankton, invertebrates and fish larvae (Bolton and Havenhand, 1998; Cole et al., 2011; Moore, 2008).

Although contamination of plastic debris in the marine environment is widely known, little research is available concerning plastic debris in fresh water settings. Zbyszewski and Corcoran (2011) reported overall quantities and distribution of plastics as well as weathering textures on fragments collected from the shoreline of Lake Huron. Eriksen et al. (2013) recently recorded the abundance of microbeads in neuston samples collected from the surface waters of the Great Lakes. Information concerning the adsorption of persistent organic pollutants (POPs) to plastics in Lake Superior (L. Rios, unpublished data) and Lake Erie (International Pellet Watch, 2005–2013) is available with polychlorinated biphenyl (PCB) concentrations in Lake Erie plastics cited as the world's third-highest. The aim of the present study is: 1) to report the distribution and abundances of plastics on the beaches of Lake Erie and St. Clair and compare the results with those previously determined from Lake Huron shorelines, 2) to illustrate the transport, and potential sources of plastic debris, and 3) to present the potential effects of shoreline type on the degradation of plastic debris in the largest freshwater system on Earth.

Materials and methods

Study area

Lakes Huron, Erie and St. Clair, which form part of the Great Lakes basin in North America, represent prime target areas for studying plastic debris because of their areal extent, relative ease of access, and surrounding population density (Fig. 1). The highly industrialized area along the eastern shore of the St. Clair River is known as “Chemical Valley” where numerous companies produce petrochemical products (Figs. 1b, c) (Environmental SWAT Team, 2005). The proximity of high population regions and industrial facilities to bodies of water has been shown to have had an effect on the abundance of plastic debris in marine settings (Gregory, 1977). In addition, Zbyszewski and Corcoran (2011) demonstrated that significant concentrations of plastic pellets were found along the Lake Huron shoreline near the location of “Chemical Valley”. We therefore anticipate that the majority of plastic debris in Lake Erie and St. Clair will be distributed near regions of high population density and industrial activity. However, additional factors that could affect the distribution of plastics in the lakes include wind and surface water circulation as well as the sediment types at different shoreline locations.

In order to fully understand the transport and distribution of low density plastic debris in the Great Lakes basin, the roles of wind and surface water movement need to be considered as well as proximity of urban centers, plastics manufacturers and beach sediment type. Weather patterns in the Great Lakes region are characterized by high-pressure systems interrupted every 3–4 days by large-scale low-pressure storm systems, largely originating in the Pacific and Arctic and, at times, in the Gulf of Mexico (Saylor and Miller, 1976). Lake Erie is the second-smallest of the Great Lakes with a length of 388 km and a breadth of 92 km (Figs. 1a–c) (State of the Great Lakes, 2005). An anticyclonic gyre dominates during the summer months with a smaller cyclonic gyre located in the western region of the lake (Fig. 1b) (Beletsky et al., 1999). During the winter months, a two-gyre current pattern is represented by anticyclonic movement in the north and cyclonic flow in the south of the lake (Fig. 1c) (Beletsky et al., 1999; Bennett, 1974). The mean magnitude of summer circulation is 1.4 cm/s, whereas winter circulation is slightly higher at 1.6 cm/s (Beletsky et al., 1999). All ten beaches sampled along Lake Erie are sandy and frequented by visitors (Table 1). The majority of the beaches along the northern shoreline are located in villages or towns where tourism and agriculture are the main industries. Along the eastern and southern shoreline of the lake, the sampled beaches are located near major cities including Buffalo, NY, Erie, PA, and Cleveland, OH. Major industries in these cities include steel and plastics manufacturing.

Lake St. Clair, which is considered part of the Lake Erie basin, receives discharge from the major outlet of Lake Huron (St. Clair River) and flows into the Detroit River before reaching Lake Erie (Figs. 1b, c). The lake is approximately 42 km long and 39 km wide with an average depth of 3.4 m, reaching only 7.6 m along the navigational channel (Fig. 1d) (Holtschalg and Koschik, 2002). The great inflow of water from the St. Clair River relative to the size of the lake causes complete water exchange to occur within 5–7 days (Gewurtz et al., 2007). The navigational channel slightly alters water current velocity, with peak bottom currents in the channel ranging from 0.3 to 0.5 m/s versus 0.1 to 0.3 m/s in other regions of the lake (Anderson et al., 2010). Peak surface current velocity in the central part of the lake ranges from 0.2 to 0.4 m/s, whereas the eastern part of the lake is characterized by near zero velocity surface currents, except during storm periods when current speed matches that occurring in the west. Of the nine shoreline localities sampled along Lake St. Clair, 6 were sandy (1 organic-rich), 1 was muddy and organic-rich, 1 was gravelly, and 1 was a concrete boat launch (Table 2). Metro Beach, Tremblay Beach and Burke Park are the only beaches heavily frequented by visitors. The area surrounding the northern, eastern and southern shoreline of Lake St. Clair is mainly agricultural; whereas, the Detroit Metropolitan area dominates the region along the western shoreline. This highly populated region has an economy dominated by the automotive industry, although some plastics manufacturers are present.

Lake Huron has an average depth of 59 m, and is 332 km long and 245 km wide (Figs. 1a, b) (State of the Great Lakes, 2005). Summer (May–October) and winter (November–April) current patterns in Lake Huron are dominated by southward flow along the western shore and a broad northward return flow along the eastern shore, thus forming a cyclonic flow pattern (Figs. 1b, c) (Saylor and Miller, 1976). The average magnitude of water circulation is 2.4 cm/s during the summer and 2.6 cm/s during the winter months (Beletsky et al., 1999). All seven beaches sampled by Zbyszewski and Corcoran (2011) were sandy and frequented by visitors (Table 3). Agriculture and/or tourism are the main industries around the lake, except for the southern region near Sarnia and “Chemical Valley” where plastics manufacturers are abundant.

Sampling and analysis

Plastic fragments along the lake shorelines were counted and sampled in 2008 (Lake Huron), 2010 (Lake Erie), and 2011 (Lake St. Clair). The general results of the Lake Huron study have been published in Zbyszewski and Corcoran (2011). Plastic material on sandy beaches was sampled by setting a 60 m transect line at each location parallel to the shoreline (Figs. 2a, b). Samples were collected at 10 m intervals from 1 m wide strips running from the water to the vegetation line. Shorelines characterized by gravel or muddy, organic-rich debris were not as extensive as sandy shorelines, and were therefore sampled from within the measured perimeter of exposure (Figs. 2c, d). In all regions, visible, <10 cm size plastic debris was carefully collected from the surface using stainless steel trowels, was placed into sealed containers, and transported to the University of Western Ontario. Items >10 cm in size were counted but were not collected.

The plastic particles were cleaned in an ultrasonic bath with deionized water for 4 min in order to remove sand and surface residue. A laboratory oven was used to dry the samples at 35 °C for approximately 45 min. The plastics were carefully separated by hand into four categories: 1) expanded polystyrene (Styrofoam), 2) pellets, 3) plastic fragments (<2 cm), and 4) intact or near-intact debris (Fig. 3). Randomly selected samples underwent Fourier Transform Infrared Spectroscopy (FTIR) at Surface Science Western using a Bruker IFS55 FTIR equipped with a microscopic stage. The samples