Plastic Pollution in the Great Lakes and Marine Waters: Sources, Effects and Policy Responses

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Plastic Pollution in the Great Lakes and Marine Waters: Sources, Effects and Policy Responses

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Abstract

Plastic wastes have generated global attention due to their ubiquitous distribution and profound environmental consequences. Global mishandling of plastic waste and low recovery rates have led to a significant rise in plastics pollution so that plastic debris that is discarded or lost during recycling efforts can travel great distances and accumulate in large quantities in terrestrial environments, shorelines, and in open freshwater and marine environments. The prevalence of single use plastics, resistance to degradation, chemical weathering, mechanical erosion, and biological degradation poses a critical environmental threat). This coupled with the long retention times of the Great Lakes lead to the conclusion that plastic pollution will be an increasing concern to ecosystem and human health in the Great Lakes presently in into the future.

Keywords: Microplastic Pollution; Great Lakes Pollution; Nanoplastic Debris; Public Policy

Introduction

Plastic wastes have generated global attention due to their ubiquitous distribution and profound environmental consequences. By way of example, the annual global production of plastic products in 2016 was about 322 million tonnes (Europe, 2016) [1]. Plastic pollution is the foremost form of debris detected in marine environments (Eriksen *et al.* 2013b, Barnes *et al.*, 2009, Gregory and Ryan, 1997) [2-4]. Plastic waste, 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) [5-7], North Pacific (Day *et al.*, 1990, Moore *et al.*, 2001) [8,9], South Pacific (Eriksen *et al.*, 2013b) [2], and in nearshore zones (Thiel *et al.*, 2013; Dubaish and Liebezeit, 2013) [10,11].

The definition of primary microplastics are those which are manufactured to have a size less than 5mm, generally found in textiles, medicines and personal care products such as facial scrubs (Cole *et al.*, 2011) [12]. The Oxford dictionary[1] defines microplastics as extremely small pieces of plastic debris in the environment resulting from the disposal and breakdown of consumer products and industrial waste. Microplastics, according to the National Oceanic and Atmospheric Association of the US, are small plastic pieces which can be harmful to our ocean and aquatic life[2]. Secondary microplastics are derived from the breakdown of plastic debris through photo-degradation, physical, chemical and biological interactions (Thompson *et al.*, 2009) [13]. The majority of microplastics in the environmental are secondary microplastics (Lee *et al* 2018) Microplastics in the environment result in a probability of break-down to nanoplastics which could more detrimental to the environmental due to their nano-particle size. Nanoplastics are <100 nm in size, and small enough to be taken up by many organisms and permeate biological membranes (EFSA Panel on Contaminants in the Food Chain, 2016) [14].

Plastic pollution loadings originate in watersheds, and are found in sewage overflows during storm events (EPA, 2007, Browne *et al.*, 2010, Browne *et al.*, 2011) [15-17]. The debris can enter through waste on beaches or from man-made structures including piers and docks (Ryan *et al.*, 2009) [18]. As summarized by Zbyszewski *et al.* (2014) [19] global mishandling of plastic waste and low recovery rates have led to a significant rise in plastics pollution so that plastic debris that is discarded or lost during recycling efforts. Debris can travel up to 100 kilometres in the atmosphere, maybe even farther (Allen *et al.* 2019) [20] and accumulate in large quantities in terrestrial environments, shorelines, and in open freshwater and marine environments. The failure of plastic recycling is illustrated in (Figure 1).

[1]https://www.lexico.com/en/definition/microplastic
[2]https://oceanservice.noaa.gov/facts/microplastics.html

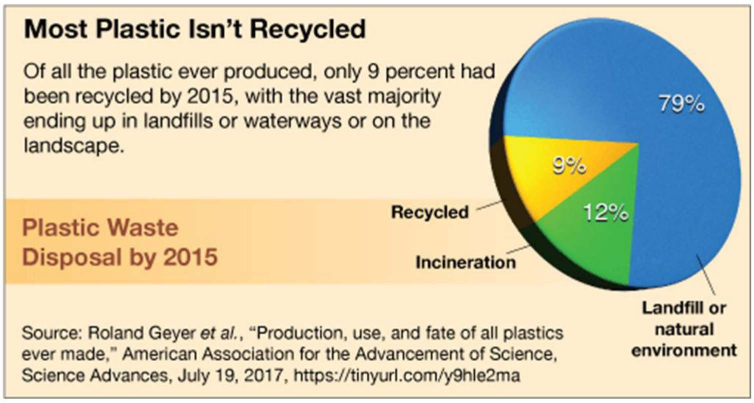

Figure 1: The failure of plastic recycling

Microplastics can form by terrestrial 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 [12,21]. Microplastics also enter the aquatic environment through direct release (Browne *et al*., 2010) [16]. 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) [22].

For example, polyethylene and polypropylene microbeads in personal care products contribute to marine pollution (Gregory, 1996, Fendall and Sewell, 2009) [23,24]. Textile laundering are also sources of microplastic fibers (Browne *et al*., 2011) [17]. The survivability of plastic has been estimated in the range of tens to hundreds of years, and degradation may be slower in cooler climates or where plastics are covered by sediment that protect them from UVB radiation (Gregory and Andrady 2003) [25].

Plastic debris can have diverse types of impact on marine ecosystems. While there are a range of debris materials in the marine environment, such as glass bottles, cans, and old nets and fishing lines, 60–80% is estimated to be petroleum-based plastic (Derraik, 2002, Browne *et al*., 2010, Browne *et al*., 2011) [16,17,26]. Jamieson *et al*. (2019) [27] detected the presence of ingested microplastics in the hindguts of Lysianassoidea amphipod populations, in six deep ocean trenches from around the Pacific Rim at depths ranging from 7000 m to 10,890 m. Hence, microplastic contaminants occur in the very deepest reaches of the oceans. Over 72% of individuals examined (65 of 90) contained at least one microparticle. A sample of microfibres and fragments were found to be composed of plastic and synthetic materials, semi-synthetic and natural fibre. They demonstrated then, that anthropogenic debris is bioavailable to organisms at some of the deepest locations in the Earth's oceans.

There is growing evidence that microplastics are ingested by marine organisms, some evidence of translocation beyond the gut and fewer still evidence of transfer from one trophic level to the next (Ng *et al*. 2018) [28]. von Moos *et al*. (2012) [29] found that microplastics were taken up by cells of the blue mussel Mytilus edulis, and that exposure to microplastics resulted in adverse effects on the tissue of the mussel. Plastic pollution impacts fish and wildlife through strangling and ingestion (Laist, 1987, Van Franeker *et al*., 2011) [30,31]. Further, persistent organic pollutants that sorb onto the plastic and can be toxic (Mato *et al*., 2001, Teuten *et al*., 2009, Rios *et al*., 2010) [32-34]. Due to their hydrophobic nature (Cole *et al*., 2013) [35], microplastics absorb polybrominated diphenyl esters, pharmaceuticals and personal care products, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons with concentrations 10^5–10^6 times higher than in the surrounding water column (Mato *et al*. 2001) [32]. When consumed, microplastics containing plasticizers such as bisphenol A (BPA) and phthalates have been found to affect hatching success and the development and reproduction. Sigler conclude that these minute plastics can make their way up the food chain, causing similar health threats to humans.

Sigler (2014) reviewed the impacts of plastic pollution on biota [36]. Wildlife can become injured due to entanglement or ingestion of the plastics. Microplastics can resemble phytoplankton which are eaten by fish and other wildlife. Ingested plastic debris creates internal injury and intestinal blockages, can cause starvation, suffocation, reduced reproductive success and mortality and growth inhibition. Since most adult birds regurgitate what has been ingested as a way to feed their chicks, they pass the plastic pieces onto their young. The plastic can obstruct and damage a bird's digestive system and growth rates. Globally, at least 23% of marine mammal species, 36% of seabird species, and 86% of sea turtle species are known to be affected by plastic debris (Stamper *et al*. 2009) [37].

To further demonstrate the severity of the matter, a sperm whale found dead on the southern coast of Spain was killed by the 29 kilos of plastic in its stomach. During an autopsy on the 10-metre long marine mammal, experts found plastic bags, fragments of nets and ropes and a jerry can. The body of the young male was found on a beach at Cabo de Palos in Murcia in February 2019. Experts from the El Valle Wildlife Recovery Center, who analysed the remains, concluded the whale had died because its digestive system became blocked and it was unable to expel the plastic it had swallowed. This caused the whale to develop peritonitis, an infection of the abdomen, which ultimately led to its death (Independent 2019) [38].

Figures 2 and 3 demonstrate pathways and effects of microplastics in biota.

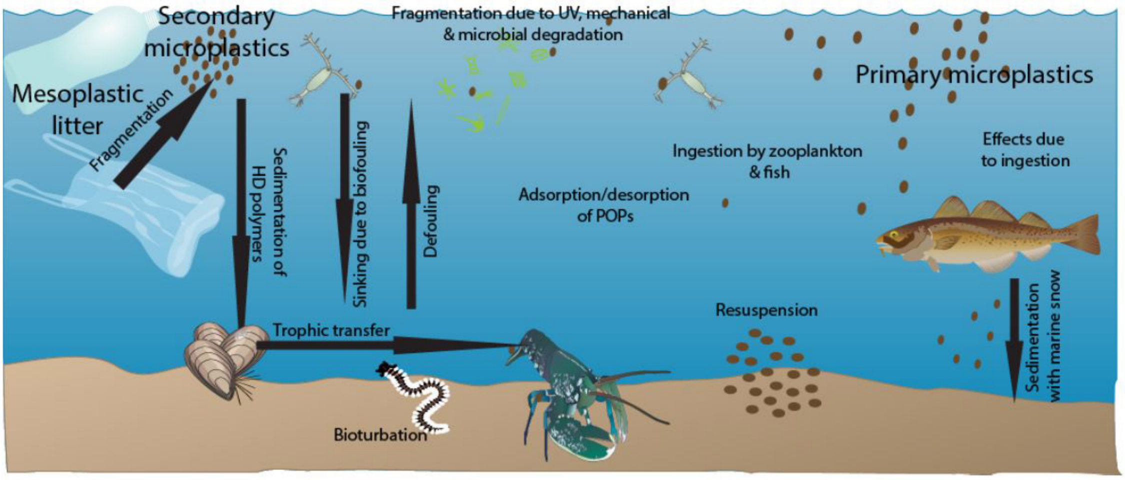

Figure 2: Potential fate and pathways and biological interactions of microplastics (from Nerland *et al.* 2014) [39]

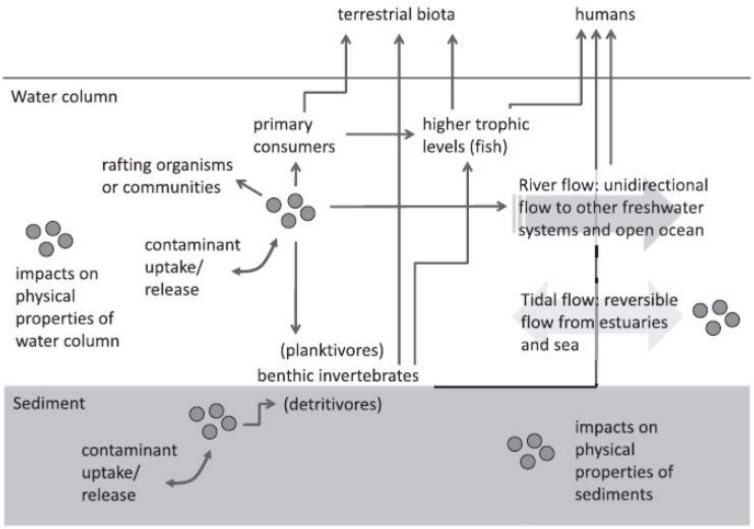

Figure 3: Diagram showing the potential transfer pathways of microplastics in freshwater systems (from Eerkes-Medrano *et al.* 2015) [40]

Plastic litter is found in marine and freshwater ecosystems all around the globe. The Laurentian Great Lakes are no exception; plastic debris is present in each of the lakes (Eriksen *et al.*, 2013a; Hoellein *et al.*, 2014; Zbyszewski and Corcoran, 2011; Zbyszewski *et al.*, 2014) [19,41,42]. Eriksen *et al.* (2013a) reported a median surface concentration of 5350 microplastic particles/km2 [41], with a maximum of greater than 466 000 particles/km2. Fragments were the most common microplastic particle in Great Lakes samples, making up 52% of particles in each sample on average. Pellets and beads made up an average of 16% of particles in each sample.

Data describing microplastic abundance in the Laurentian Great Lakes tends to be focused on beach surveys (Zbyszewski and Corcoran, 2011) [43]. Given that the watersheds surrounding the Great Lakes are heavily urbanized (for instance, Chicago, Milwaukee, Detroit, Cleveland and Buffalo in the United States, and Toronto in Canada), plastic pollution in the Laurentian Great Lakes is a threat to the integrity of the ecosystem and could be expected to increase in intensity. Baldwin *et al.* (2016) [44] characterized the quantity and morphology of floating micro- and macroplastics in 29 Great Lakes tributaries in six states under different land covers, wastewater effluent contributions, population densities, and hydrologic conditions. They found plastics in all 107 samples, with a maximum concentration of 32 particles/m3 and a median of 1.9 particles/m3. Virtually all particles were microplastics. As one might predict, litter-related plastics (fragments, foams, and films) were found at higher concentrations in samples from more urban watersheds and during runoff-event conditions. Baldwin *et al.* (2016) [44] explain that not only is plastic litter more prevalent in urban watersheds than in areas with other land covers, but it is also more mobile because impervious surfaces and storm sewers facilitate conveyance of plastics to receiving water bodies during runoff-event conditions. This is consistent with the findings of Yonkos *et al.* (2014) [45] who reported a correlation between microplastic concentrations, population density and urban/suburban development.

Municipal wastewater treatment plants (WWTPs) are frequently suspected as significant point sources of microplastics to the environment. Carr *et al.* (2016) [46] investigated effluent discharge from seven tertiary plants and one secondary plant in Southern California, which varied in influent loading, conveyance and removal of plastics. The results suggested that tertiary effluent was not a significant source of microplastics and that these plastic pollutants were effectively removed during the skimming and settling treatment processes. However, at the secondary plant, an average of one micro-particle in every 1.14 thousand liters of final effluent was measured. Recent studies reviewed by Gies *et al.* (2018) [47] highlight that between 50,000 and 15 million microplastics per day were discharged from WWTPs, predominantly fibres and fragments which can originate in part from the washing of synthetic clothing in household laundry and abrasives from some cosmetic products and toothpastes. In their study of microplastic release from a plant in Vancouver, 97-99% removal efficiencies were found. Yet Kay *et al* (2018) [48] found wastewater treatment plants to be a key source of microplastic in the river catchments they studied in England stating that "[t]he fact that the quantity of microplastics present in receiving waters was greater downstream of each of the six wastewater treatment plants studied confirms that treated sewage effluent is a key source of microplastics." It appears that the loading from wastewater treatment plants remains unknown, with some plants operating at much greater efficiencies than others.

On a personal note, I was visiting a waterfront park in the Toronto region in the fall of 2018 just after a major storm event. The plastic litter on the shoreline was dramatic, and my point of observation was near the outfall of a combined sewer. Figure 4 shows this type of accumulation in nearshore zones of the Great Lakes.

Figure 4: Plastic pollution in the nearshore of the Great Lakes 2018 (photo credit Alliance for the Great Lakes https://greatlakes.org/2018/05/adopt-a-beach-team-of-the-week/)

Policy Landscape

A conservative estimate of the overall economic impact of plastics to marine ecosystems is ~$13 billion US/year although the true environmental costs are difficult to monetize. However, reported impacts of marine plastic debris on marine life include nearly 700 species, from zooplankton to whales, including fish destined for human consumption. Of the hundreds of marine species impacted, 17% are IUCN red listed species and at least 10% have ingested plastics (Xanthos and Walker 2017) [49].

The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), which came into effect 1973, included requirements to prevent the disposal of plastics at sea. More recently, the Honolulu Strategy provided a framework to internationally reduce plastic waste, and represents an international management structure designed to meet the specific needs of different countries including Canada. The Honolulu Strategy is intended for use as a:

- Planning tool for developing or refining spatially or sector-specific marine debris programs and projects
- Common frame of reference for collaboration and sharing of best practices and lessons learned
- Monitoring tool to measure progress across multiple programs and projects

The Honolulu Strategy is a framework document. It does not supplant or supersede activities of national authorities, municipalities, industry, international organizations, or other stakeholders; rather, it provides a focal point for improved collaboration and coordination among the multitude of stakeholders across the globe concerned with marine debris. Successful implementation of it requires participation and support on multiple levels—global, regional, national, and local—involving the full spectrum of civil society, government and intergovernmental organizations, and the private sector (NOAA nd) [50]. Pettipas *et al.* (2016) [51] summarize that the strategies include market-based instruments (e.g., levies on single-use plastic bags) for reducing waste and legislation to reduce marine debris (e.g., imposing bans on single-use plastic microbeads and/or plastic bags). In evaluating effectiveness of certain tools, following the introduction of the five pence levy in England, plastic bag use at major supermarkets dropped by 85%; equivalent to approximately six billion fewer bags issued during the first year of implementation (Xanthos and Walker, 2017) [49].

Bans, partial bans, and fees have been enacted by some local jurisdictions in North America, but in most cases, national approaches have been undertaken (e.g., across many European countries). Xanthos and Walker (2017) review such intiatives [49]. They report that "bans, partial bans, and fees have been enacted by some local jurisdictions in North America, Australia, and the United Kingdom. Some countries in Europe where interventions are widespread, impose a fee per bag. Germany and Denmark were early adopters of plastic bag bans in most retail stores in 1991 and 1994. However, since 2002, countries in Africa, Asia, and the rest of Europe have steadily introduced bans (South Africa, Bangladesh and India) or levies (Ireland) on plastic bag consumption. In most cases, national approaches have been undertaken. Several countries in Africa and Asia completely banned the use of plastic bags."

In looking to other jurisdictions for policy development and implementation, it is notable that that federal bans for single-use microbeads have been deployed successfully. Consistent with this direction, the Canadian government classified plastic microbeads as toxic, under the Canadian Environmental Protection Act. On January 1, 2018, the Canadian federal government banned wash-off toiletries and cosmetics containing microbeads from stores in Canada (Pettipas *et al*., 2016) [51].

The urgency for Canada to act swiftly to curb the vast amounts of plastic waste produced has intensified since China stopped importing recycled film plastic from developed countries (Walker, 2018) [57]. As Xanthos and Walker (2017) [49] report, many countries especially those across Europe, have already successfully implemented bans of single-use plastic bags. Other policies to reduce single-use plastics as summarized by Walker and Xanthos (2018) [52] include banning plastic single use plastics such as drinking straws, deposit/ return systems for plastic bottles and extended producer responsibility, which makes producers responsible for the entire product life-cycle.

Going beyond Canada, and looking to the Great Lakes regions, plastic waste management is arguably the responsibility of municipal government. To this end, the Great Lakes and St. Lawrence Cities Initiative (GLSLCI) [53], a binational coalition of mayors and municipal officials that seeks to advance the protection and restoration of the Great Lakes and the St. Lawrence River, have used their leadership and pronounced microplastics as a significant threat to the Great Lakes region. GLSLCI has adopted a resolution that calls on industry to phase out microbeads from consumer products, including personal care products. The resolution further calls on provincial, state, and federal governments to establish legislation banning the use of microbeads in consumer products (Great Lakes and St. Lawerence Cities Initiative, 2014) [53]. According to Driedger *et al*. (2015) [54] a ban on the manufacture and sale of personal care products containing microbeads has become law in Illinois, with comparable legislation been introduced in New York, California, Michigan, and Ohio, and is being considered in Wisconsin, Pennsylvania, Ontario, and Québec, while Minnesota has passed a bill requiring that the issue be investigated [55-57].

So, while plastic waste management falls as a responsibility for municipal government, federal bans on single-use plastics (including single-use plastic bags and other items such as, plastic drinking straws, plastic cutlery, and plastic packaging) and microbeads, is plausible and could be more effective than less coordinated efforts initiated by different municipalities at their choosing.

Concluding Remarks

The prevalence of single use plastics, resistance to degradation, chemical weathering, mechanical erosion, and biological degradation poses a critical environmental threat (Zbyszewski *et al*. 2014) [19]. This coupled with the long retention times of the Great Lakes lead to the conclusion that plastic pollution will be an increasing concern to ecosystem and human health in the Great Lakes presently in into the future.

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