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Review

Microplastics in aquatic environments: Implications for Canadian ecosystems[☆]Julie C. Anderson^{a, *}, Bradley J. Park^b, Vince P. Palace^{a, 1}^a Stantec Consulting Ltd., 500-311 Portage Ave., Winnipeg, MB R3B 2B9, Canada^b Fisheries and Oceans Canada, 501 University Crescent, Winnipeg, MB R3T 2N6, Canada

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ABSTRACT

Microplastics have been increasingly detected and quantified in marine and freshwater environments, and there are growing concerns about potential effects in biota. A literature review was conducted to summarize the current state of knowledge of microplastics in Canadian aquatic environments; specifically, the sources, environmental fate, behaviour, abundance, and toxicological effects in aquatic organisms. While we found that research and publications on these topics have increased dramatically since 2010, relatively few studies have assessed the presence, fate, and effects of microplastics in Canadian water bodies. We suggest that efforts to determine aquatic receptors at greatest risk of detrimental effects due to microplastic exposure, and their associated contaminants, are particularly warranted. There is also a need to address the gaps identified, with a particular focus on the species and conditions found in Canadian aquatic systems. These gaps include characterization of the presence of microplastics in Canadian freshwater ecosystems, identifying key sources of microplastics to these systems, and evaluating the presence of microplastics in Arctic waters and biota.

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1. Introduction

Plastic is a general term that refers to a family of organic polymers derived from petroleum sources, including polyvinylchloride (PVC), nylon, polyethylene (PE), polystyrene (PS), and polypropylene (PP) (Vert et al., 2012). Common plastic polymers include PP, PE, low-density polyethylene (LDPE), and polyacrylates (Imhof et al., 2013; Frias et al., 2014; Hidalgo-Ruz et al., 2012). Plastic production and use has increased steadily over the past 50 years, with global production reaching over 300 million tonnes in 2014 (Plastics Europe, 2015). These usage patterns suggest that plastic production and quantities of plastics (including microplastics) in aquatic environments will likely continue to increase over time (Andrady, 2011; Galgani et al., 2010). The defined size of a particle constituting a “microplastic” varies, but an upper limit of 5 mm is generally agreed upon in the literature, and many researchers use 0.5 or 1 mm as the cut-off between macro or mesoplastic and

microplastic (Andrady, 2011; Cole et al., 2011). Prior to about 2010, studies typically investigated plastic particles ranging from 1 to 5 mm, and data relevant to smaller particle sizes are scarce prior to that time (Claessens et al., 2011).

Microplastics may pose a risk to aquatic environments due to their documented ubiquity in marine ecosystems, long residence times, and propensity to be ingested by biota (Arthur et al., 2008a; Galgani et al., 2010; Andrady, 2011). While studies and reviews on plastic pollution in the marine environment are increasingly common, to date, few studies have assessed the presence, fate, and effects of microplastics in freshwater environments. Even fewer studies have been completed in Canada, despite the fact that 7% of the world's renewable freshwater is contained within these water bodies (Environment Canada, 2012). While the presence, sources, fate, and effects of microplastics have not been well characterized in freshwater systems, evidence from the marine environment suggests that microplastics could be considered contaminants of emerging concern (Wagner et al., 2014; Eerkes-Medrano et al., 2015).

In response to growing concerns from the scientific community regarding microplastics, the Netherlands, Austria, Luxembourg, Belgium, and Sweden issued a joint statement to the European Union Environment Ministers calling for a ban on microplastics in

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personal care products (UNEP, 2015). Likewise, bans on microplastics in cosmetic products were enacted in Illinois (Hitchings, 2014), California (Doughty and Eriksen, 2014), and New York (Office of the New York State Attorney General, 2015), and finally were signed into US federal law (*Microbead-Free Waters Act of 2015*) in January 2016. In mid-2015, the Government of Canada proposed to include microbeads on the List of Toxic Substances under the *Canadian Environmental Protection Act, 1999* (Environment Canada, 2015).

There were several objectives for this review, all of which were approached with Canadian aquatic ecosystems as the primary focus. First, we sought to summarize: a) inputs and composition of microplastic materials in the Canadian aquatic environment; b) their environmental fate and behaviour, including previously reported environmental levels of various size classes in surface waters, vertically throughout the water column, and in sediments; and c) pathways of ingestion by biota (direct ingestion and trophic transfer) and persistence in tissues. Second, the toxic potential of microplastics in aquatic biota, including invertebrates, fish, and mammals was summarized. Finally, knowledge gaps were identified to inform future work on the aquatic toxicity of microplastics.

2. Methods

To conduct this review, combinations of keywords (i.e., microplastic(s), microbead(s), freshwater, aquatic, Canada, presence, effect(s), toxicity) were entered into Stantec's Research and Development Resource eLibrary holdings (including articles from Elsevier, Scopus, JSTOR, EBSCOhost, and Science Direct). These holdings contain over 5700 journals available in full-text format. In addition, supporting searches were conducted using Google Scholar and the University of Manitoba libraries guest services, with literature considered up to and including articles available as of January 2016. Articles were selected for inclusion in this review based upon the relevance of the information to the topic of microplastics in the Canadian aquatic environment, as judged by the authors, as well as inclusion in or agreement with other peer-reviewed articles. Articles were usually considered if self-identified as studying "microplastics", but a threshold of 5 mm was used for excluding macroplastics. Studies in which microplastics were quantified in Canadian waterbodies were considered of greatest interest. Where information specifically pertaining to Canadian ecosystems was not available, data from international studies were included to help establish the current level of understanding of microplastics in aquatic environments. While the present review may not be an exhaustive summary of the literature, the authors believe it represents an accurate portrayal of the current state of knowledge regarding microplastics in the Canadian aquatic environment.

3. Sources and fate of microplastics in the aquatic environment

3.1. Sources of microplastics

In general, microplastics fall into two categories: they are either produced intentionally (e.g., microbeads, plastic production pellets) and called "primary microplastics" or are degraded from larger plastic to smaller pieces (e.g., fibres) and are called "secondary microplastics" (Cole et al., 2011; Gilman, 2013; Andersson, 2014). In Canada and globally, primary microplastics (often PE microbeads) have been added to a variety of personal care products, including toothpastes, shampoos, facial cleansers and moisturizers, cosmetics, and shaving products for emulsion stabilization, viscosity regulation, and skin conditioning (Cole et al., 2011; Derraik, 2002;

Driedger et al., 2015; Leslie, 2014). A study of six brands of facial scrubs reported that between 4594 and 94,500 microbeads (164–327 µm in diameter) could be released into the wastewater stream per use of the products (Napper et al., 2015). Microplastics are also added to industrial cleaning products (e.g., scrubbers for removal of rust or paint) (Derraik, 2002; Cole et al., 2011), and pellets are used in production of plastic consumer goods (Mato et al., 2001; Turner and Holmes, 2015). Ultimately, any of these forms of plastic has the potential to end up in municipal wastewater and freshwater systems (Cole et al., 2011; Doughty and Eriksen, 2014; Leslie, 2014).

It has been proposed that freshwater systems can become contaminated by microplastics in one of three ways: 1) effluent discharge from wastewater treatment plants, 2) overflow of wastewater sewers during high rain events, and 3) run-off from sludge applied to agricultural land (Eriksen et al., 2013a). The directional flow of freshwater systems typically drives microplastics to river bottoms, lake bottoms, and the oceans, which become sinks. It has been estimated that approximately 80% of microplastics in oceans originate from land-based sources, and another 18% from aquaculture or fishing industries (Andrady, 2011; Cole et al., 2011). Storms and extreme weather events can also exacerbate the movement of microplastics from land into bodies of water (Cole et al., 2011). Most current wastewater treatment plants (WWTPs) are not designed to fully remove microplastics (Fendall and Sewell, 2009; Leslie et al., 2013). For example, in a Paris WWTP, raw influent contained $260\text{--}320 \times 10^3$ particles/m³ that was reduced to $50\text{--}120 \times 10^3$ particles/m³ after primary treatment, and $14\text{--}50 \times 10^3$ particles/m³ in the final effluent. This represents removal of between 83 and 95% of microplastics (Dris et al., 2015a). Likewise, an assessment of a Helsinki WWTP reported ~97% removal of microplastic fibers and 98% removal of microplastic particles, but the effluent levels were still elevated relative to receiving waters, indicating that the WWTP represented a source of microplastics to the receiving environment (Talvitie et al., 2015). In Canada and the US, WWTPs are not currently required to monitor microplastics in effluents or influents (Driedger et al., 2015) and many WWTPs do not have any sort of advanced treatment (i.e., tertiary treatment), and therefore, optimized removal of microplastics would not be expected (CWWA, 2001; Office of the New York State Attorney General, 2015; Talvitie et al., 2015). Even when sewage sludge is applied to agricultural lands, plastic fibers can persist (i.e., 15 + years) and migrate off fields via runoff during storm events (Zubris and Richards, 2005).

3.2. Environmental fate and behaviour

Plastics consist of different polymers that can be buoyant, neutral, or sink, depending upon composition, density, and shape of the plastic (Fig. 1). PP and PE are typically low-density plastics that are expected to be relatively buoyant, while PVC, PS, polyester, and polyamide are considered high-density plastics that are more likely to sink (Browne et al., 2007; Cole et al., 2011). However, PE and PP can become higher density polymers as a result of addition of mineral fillers during production (Corcoran, 2015; Corcoran et al., 2015). Approximately half of manufactured plastics have a density higher than seawater (Ballent et al., 2013), and denser varieties, such as polyester, tend to submerge or even reach the sediment (Andrady, 2011). Turbulence and storm activity can cause (re-) suspension of high-density microplastics and redistribution throughout the water column (Moore et al., 2002; Lattin et al., 2004; Cole et al., 2011). Biofouling can occur, as can adsorption of clay minerals, increasing the density and weight of the microplastic particle and resulting in sinking to pelagic or benthic zones (Andrady, 2011; Cole et al., 2011; Corcoran, 2015; Corcoran et al.,

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