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Literature Review

Microbeads: "Tip of the Toxic Plastic-berg"? Regulation, Alternatives, and Future Implications

Submitted to the United States Embassy of Ottawa
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2 – Executive Summary

This literature review was carried out as part of the graduate *Capstone Practicum* of the Institute for Science, Society and Policy at the University of Ottawa. The seminar participants collaborated in a literature review on issues associated with microbeads—small plastic particles used as abrasives or fillers in cosmetic and personal care products.

The literature review covers three questions in the context of microbeads. (1) What is the comparative state-of-affairs of the current and planned federal regulations in Canada and the United States? (2) What can we expect to see in terms of replacement products and are there any safety concerns with those? (3) How does the current concern over microbeads in personal care products relate to micro-plastics from other sources, for example from the breakdown over larger plastic products? Each of these questions is addressed in one of the main chapters in this report (chapters 7-9). We conclude with a brief discussion on some of the policy implications of this big picture literature review (chapter 10).

The two nations are quite well-aligned with respect to public concern and regulatory activities. Private industry and governments at all levels in North America are already moving ahead to phase out microbeads in personal care products. In 2014, Illinois became the first jurisdiction in the world to ban products from containing microbeads. This set a precedence for eight other states and the American federal government to enact similar laws, including the state of California which became the first jurisdiction in the world to ban the use of all microbeads, including *biodegradable* microbeads. At the federal level, President Obama signed into law the "*Microbead-Free Water's Act of 2015*" on December 28, 2015, which prohibits the manufacture and introduction of rinse-off cosmetics containing plastic microbeads as of July 2017.

Concerns over the harmful environmental impacts of microbeads is also pushing Canada to develop similar laws. The Government of Canada has committed to add microbeads to the federal *Toxic Substances List* and Environment and Climate Change Canada (ECCC) is in the process of proposing a regulation that would ban microbeads as of December 2017. At the provincial level, Ontario is also proposing to regulate microbeads, and could become the first jurisdiction in Canada to ban them.

Concerns over the lack of harmonization in the definition of microbeads, and a lag time between implementation of legislation between the two federal jurisdictions, has led some commentators and environmental groups to state that Canada may "under-regulate" microbeads (and, thus, become a "dumping ground"). However, both federal jurisdictions are proposing to include *biodegradable* microbeads in their ban, which is seen as a measure that will strengthen the regulations and reduce the amount of microbeads entering the environment.

Replacement products are already available to producers and consumers of cosmetic and personal care products. Examples include: coffee grounds, pumice, coconut shells, and sugar. These alternatives have not attracted much attention in the academic literature, therefore their environmental impacts and their suitability for mass market are unknown. Biodegradable polymers (PHA), have been developed as a promising alternative. However, it is unclear whether these products will be classified (and therefore banned) by the definition of 'biodegradable' in the new legislation. The impacts of these biodegradable microbeads in cosmetics on the environment are also unknown.

As a result, there is little proof that replacement products will be clearly superior in terms of risks to the environment or human health. Nevertheless, it is a fact that plastics remain virtually forever in the natural environment, while most candidate replacement products do not. On the basis of persistency alone, it seems desirable to ban microbeads and "hope for the best" when it comes to the substances that eventually will take their place in cosmetic and personal care products.

Plastic waste enters the environment through mismanagement and are eventually fragmented and degraded into "secondary microplastics." The processes that cause plastics to degrade are well understood, but the rate at which plastic debris is degraded into microplastics is still uncertain. However, it *is* quite certain that the amount of secondary microplastics in the oceans is much larger than the amount of "primary" microplastics such as microbeads. It is also quite certain that the environmental effects of primary and secondary microplastics are identical. We can, therefore, argue that microbeads are really just the "tip of a toxic plastic-berg." The larger, lesser known part of this "plastic-berg" will likely require some policy attention in the near future since the health of the oceans and fisheries are now a globally recognized issue.

Policy measures proposed in the literature are focused on waste management and recycling programs. It would be worth to also consider the innovation potential new technologies (such as nanotechnology and biotechnology) and social innovations. Finally, we have to recognize that policy thinking will have to be global and involve stakeholders associated with the entire life-cycle of plastics. The coordination of research through the development of clear concepts, definitions, typologies and methods alone is a major challenge. The development of internationally harmonized regulations is an even greater challenge. Finally, the implementation of regulations at this scale and in this space (the global commons of the high seas) is daunting. Our literature review led us to believe that this problem is important and urgent enough that these challenges need to be addressed.

3 – Timeline

Year	Event
1907	First truly synthetic polymer, Bakelite developed.
1910-1950	Development of modern plastics expands. 15 new synthetic polymers developed, including the most common commodity plastics in use today.
1950's	Large-scale industrial production of plastics begins.
1960's	First documentation of plastic debris impacts on wildlife (GESAMP summary).
1960's	First patents for personal care microbeads issued as identified by the IJC.
1970's	Small pieces of floating plastics reported on the ocean's surface (see GESAMP summary).
1980's-1990's	Observations of plastics in marine environment increases rapidly.
1990's	Use of microbeads in personal care products expands as identified by IJC.
1990-2004	Use of "microplastics" appears in literature. Exact date of first use uncertain.
2004	First major scientific publication dedicated to microplastics (see Thompson *et al.*, 2004)
2006	Canada's Chemicals Management Plan is launched.
2008	National Oceanographic and Atmospheric Administration (NOAA) hosts first international workshop on microplastics pollution
2011	Global plastics industry issues declaration committing itself to contribute to solving the global marine litter problem.
2012	North Sea Foundation and Plastic Soup Foundation launch Smartphone application as part of "Beat the Bead" Campaign.
June 2012	Global Partnership on Marine Litter (GPML) established with the objective of protecting human health and the environment.
December 2012	Industry begins to respond to pressure to remove plastic microbeads from personal care products.
Summer 2013	United Nation Environmental Program backs the "Beat the Bead" campaign.
June 8, 2014	Illinois becomes the first state to ban the use of microbeads, restricted to rinse-off cosmetics, allows biodegradable microbeads, excluding prescription drugs.
March – July 2015	Maine, Colorado, New Jersey, Indiana, Maryland, and Connecticut ban the use of microbeads, restricted to rinse-off cosmetics, allows for biodegradable microbeads.
October 8, 2015	California becomes the first jurisdiction in North America to ban the use of biodegradable microbeads.
March 9, 2015	Legislative Assembly of Ontario discusses Bill 75 - Microbead Elimination and Monitoring Act, 2015
March 24, 2015	The Canadian House of Commons unanimously votes for the federal government to take immediate measures and add microbeads to the Toxic Substances List (section 1.1).
June 22-23, 2015	The Canadian Council of Ministers of the Environment voice their support for Environment Canada (EC: renamed as of 2016 to Environment and Climate Change Canada, ECCC) to conduct a scientific review on microbeads (section 2.3.1).
July 30, 2015	EC completes a scientific assessment of microbeads. The report recommends that microbeads should be added to the Toxic Substances List.
August 1, 2015	*Notice of Intent* is published stating that EC is initiating the development of proposed regulations under CEPA 1999 to regulate microbeads.
December 28, 2015	President Obama signs into law the *Microbead-Free Waters Act of 2015,* prohibiting soaps, body washes, toothpaste, and other personal-care products from containing microbeads as of July 2017.
March 10, 2016	Environment and Climate Change Canada (ECCC) public consultation followed by a 30-day comment period closing on March 10, 2016 (section 6.2).

4 – Glossary

Word or Acronym	Explanation or Definition
Biodegradation	Biological process of organic matter, which is completely or partially converted to water, CO_2, methane and new biomass by microorganisms (bacteria & fungi).
Canadian Environmental Protection Act, 1999 (CEPA)	Canada's most comprehensive federal legislation terms of pollution prevention, protecting human health and the environment.
Chemicals Management Plan (CMP)	Regulatory framework for monitoring, assessing, and regulating the effects of chemical substances in Canada.
Commodity Plastic	Widely used, most commonly produced plastics. Includes polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyurethane (PUR) among others.
Compostable	Capable of being biodegraded at elevated temperatures in soils under specific conditions and time scales, usually only encountered in an industrial composter.
Degradation of polymers	The partial or complete breakdown of a polymer as a result of e.g. UV radiation, oxidation, biological processes. This may include the alteration of the properties, such as discolouration, surface cracking and fragmentation.
Domestic Substances List (DSL)	Substances that were, between January 1, 1984, and December 31, 1986, manufactured in, imported into, or used in Canada on a commercial scale.
Fisheries Act	Canadian federal act that includes a prohibition for the release of toxic or harmful chemicals into fish habitats.
Food and Drugs Act (FDA)	Canadian federal act that governs foods, drugs, natural health products, cosmetics and medical devices sold in Canada.
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GPML	Global Partnership on Marine Litter
IJC	International Joint Commission
Macroplastic	Generally refers to plastic particles that are large enough to be seen with the naked eye. Use of macroplastic ubiquitously refers to larger obviously visible plastics. *Note: Definition of macroplastics in not internationally agreed upon.
Microplastic	Generally refers to plastic particles with an upper size limit of 5mm in diameter. Use of microplastics ubiquitously refers to 'small' pieces of plastic. *Note: Definition of microplastics is not internationally agreed upon.
Mineralization	Defined here, in the context of polymer degradation, as the complete breakdown of a polymer as a result of combined abiotic and microbial processes, into CO_2 water, methane, hydrogen, ammonia and other simple inorganic compounds.
Oxo-degradable	Containing a pro-oxidant that induced degradation under favourable conditions. *Note: Complete breakdown of the polymers and biodegradation still have to be proven.
PBiT	Classification of substances based on persistency, bioaccumulation, and inherent toxicity as outlined in the *Canadian Environmental Protection Act, 1999*.
Pest Control Products Act (PCPA)	Canadian federal law that regulates products used for the control of pests and the organic functions of plants and animals.
Plastic	In the context of microplastics, plastic refers to a sub-set of the larger class of materials called polymers.
Primary Microplastic	Microplastics originally manufactured to be small in size. Example: Abrasives, cosmetic exfoliants, industrial processes, raw plastic pellet 'feedstock'.
Secondary Microplastic	Microplastics resulting from the mechanical, chemical or physical fragmentation of larger plastic objects.

5 – Introduction

5.1 Background

Microbeads are small plastic particles used as exfoliates in consumer and personal care products such as shampoos, soaps, lip gloss, and toothpaste. They also find application in abrasives, cleaning products, and medical devices. Microbeads can be defined as small plastic particles with a diameter between 0.1µm and 5 mm (Environment Canada, 2015a). Definitions vary among jurisdictions, however (for example, the US definition uses the same upper size limit but does not specify any lower size limit; more on this below). Because microbeads are manufactured to be small, they are referred to as "primary microplastics". This is in contrast to equally small particles found in nature that are the result of the decay of larger plastic products and that referred to as "secondary microplastics."

A single cosmetic product can contain 5000 to 95,000 microbeads (Napper *et al*., 2015). Since most microbeads are tiny, most water treatment facilities are unable to process these particles before they are discharged into the environment. Recent scientific evidence suggests that microplastics, such as microbeads can be considered toxic substances, and a serious environmental concern for aquatic habitats and wildlife and have the potential to contaminate food chains (Thompson *et al.*, 2009a; Cole *et al*., 2011; STAP, 2011; Eriksen *et al*., 2013; Wright, Thompson, & Galloway, 2013; Gall & Thompson 2015; Green *et al*., 2016).

Consumer and advocacy groups have urged industry to remove products containing microbeads and replace them with alternatives (Plastic Soup Foundation, 2016). In response, the supermarket chain Loblaws and companies such as Johnson & Johnson and L'Oréal have committed to phase out microbeads from their products (Copeland, 2015).

In the US, President Obama signed into law the "*Microbead-Free Water's Act of 2015*" on December 28, 2015, which prohibits the manufacture and introduction of rinse-off cosmetics containing plastic microbeads (Microbead-Free Waters Act of 2015). Other jurisdictions including Canada, Austria, Belgium, the Netherlands, Luxembourg and Sweden are also calling for a ban of microbeads in personal care products (Perschbacher, 2016). On March 24, 2015, the Canadian House of Commons voted unanimously for the government to take immediate measures to add microbeads to the *List of Toxic Substances*, which would ban their manufacture, import, and sale on the market and could come into effect as early as December 2017 (ECCC, 2016).

The interconnections and collaborations between US and Canadian interests are, of course, manifold. The two countries are the largest trading partners in the world. Initiatives to harmonize (or "align") regulations exist at the highest level of governments through the *Regulatory Cooperation Council* (RCC). Finally, through the *International Joint Commission* (IJC), Canada and the United States regulate shared waters and collaborate to resolve and manage transboundary environmental and water issues, including the microbead file (IJC, 2016b). It is, therefore, of interest to compare the state of regulation between the two countries and also chart anticipated future issues for the microbeads file.

Looking forward, it should also be of interest to evaluate the state-of-affairs when it comes to replacing microbeads in personal care products. It is certainly of public interest that products will become safer for humans and the environment, rather than containing less-safe alternative abrasives in the future.

Taking an even broader lens, the consideration of secondary microplastics puts the cosmetic microbead issue into a much broader pollution context. Global plastic production has increased six-fold since 1975 and was estimated to be almost 300 million metric tonnes in 2015 (PlasticsEurope 2015a). Macroscopic plastic waste can generate different types of plastic in the environment. The waste may remain macroscopic in the form of plastic bottles and bags, or breakdown to secondary microplastics (Environment Canada, 2015a). Cole *et al*. (2011) estimated that 10% of global plastics will enter the oceans. Due to wave energy and other factors, physical breakdown of these plastic to secondary microplastics is common. Since global plastic production is still increasing, and since most plastics are chemically highly persistent, the problems associated with both macroplastics and microplastics will continue to accumulate over time. Even from the narrow perspective of economics (that is often unable to fully account for environmental, health and social costs and that will exclude non-economic "costs" such as the suffering of wildlife), UNEP (2014a) "conservatively" estimated that plastic waste already causes financial damage of $13 Billion (US) to marine ecosystems annually. Considering that there is no reason for why the environmental effect of primary and secondary microplastics should be any different, it is meaningful to look at this broader context that may become of interest once the new cosmetic microbead legislations are fully designed and implemented. Are microbeads just the "tip of the toxic plastic-berg"?

5.2 Our Charge

In January 2016, the Embassy of the United States (Ottawa) commissioned the graduate students enrolled in the Capstone Practicum of the University of Ottawa's Institute for Science, Society and Policy to conduct this literature review on regulation, alternatives, and future implications concerning microbeads.

Per our proposal, dated February 16, 2016, we have agreed that the literature review should encompass the following three themes:

- Regulatory frameworks in place to manage chemical substances in Canada and the US and progress on regulating microbeads in Canada;
- Industry alternatives and concerns with the replacement products; and
- Possible implications for the future regulation of similar products in both countries.

We also agreed to keep the scope of this literature review policy- rather than science-oriented with the aim to be informative for senior management and decision-makers and an approximate length of 30 pages.

Accordingly, our literature review proceeds in Section 6 with a description of the methods used. Section 7 presents an overview of chemical management and microbead regulation in Canada and the United States, and follows with a discussion on policy challenges with microbead regulation. Section 8 discusses industry alternatives to microbeads, and Section 9 frames plastic pollution in the global context. It also speaks to current and future research directions, and identifies policy challenges for microplastic pollution. Section 10 will summarize the state-of-knowledge and explicitly compare the "known" and the "unknown" for the three contexts (regulations, alternatives, and beyond microbeads).

6 – Methods

6.1 Process

This literature review has been completed as part of the graduate course "ISP5903," a capstone practicum required by the University of Ottawa's *Institute for Science, Society and Policy* to obtain the designation of "specialization in science, society and policy" for eligible masters' programs. The research team consulted with the collaborative United States Embassy in Ottawa, on February 3, 2016. This meeting resulted in the commissioning of a literature review that focused on the regulation, alternatives, and future implications of microbeads. To plan, discuss and complete this literature review, weekly classroom meetings were held (3h per week). The client was sent a research proposal and an annotated table on contents on March 3. Communications with the embassy were carried out through e-mail and a 30-minute telephone conversation on March 17, 2016, where comments and feedback were provided. On March 31, 2016, a draft copy of the completed literature review was sent for comments. Results will be presented to the United States Embassy on April 14, 2016.

6.2 Scope

We gathered literature from academic and "gray" literature, as well as the media, and web sources. A series of key terms (**Table 1**, below), were used to search academic articles, articles in press, reports, and other sources of grey literature in five digital databases: Google Scholar, JSTOR, Political Science, Science Direct, and CABI. Additionally, grey literature such as industry reports and non-governmental organization (NGO) documents and news articles were included in our search. The review focused on literature published from 2009 to 2016 and was limited to publications in English. A total number of over 100 documents were collected and consulted in the process of producing this literature review.

Table 1– Sample keywords used in our literature searches

Major Keywords	Source	AND	AND	AND
	<u>Microbeads</u>	Canadian and United States legislation	Alternatives	Future implications
OR	Primary microplastics	Chemical management	Commercial	Impact
OR	Secondary microplastics	Chemical regulation	Production	Health
OR	Plastic waste	Management framework	Natural	Environment
OR	Pollution	Regulatory process	Replacement	Policy
OR	Debris	Regulatory framework	Substitute	Life-Cycle

The methodological approach varied slightly among different sections:

Section 7 focuses on the review of various federal governmental websites such as Environment and Climate Change Canada, Health Canada, Natural Resources Canada, Fisheries and Oceans Canada, Department of Justice, Environmental Protection Agency, and the Food and Drug Administration. We consulted these sources to gain a better sense of the regulatory landscape of chemical management in Canada and the United States. Environmental NGO groups such as Sierra Club, Environmental Defence, Canadian Environmental Law Association, and Ecojustice Canada provided literature that comments on these policies.

Section 8 places a greater emphasis on grey literature and media sources including blogs, newspaper articles, organic/natural information websites, and magazines. The search strategy for this section led to few academic papers covering this topic. The grey literature and media sources were found using Google as a search engine, while academic sources used stemmed from JSTOR, CADI, Google Scholar and Science Direct.

Section 9 on 'big picture' issues and future implications of microbeads regulations emphasizes academic literature, however relevant grey literature and media articles were included. Articles for this research were found using the database Google Scholar, and media articles were located using a Google news alerts with the keywords "microplastic" and "microbeads".

It should be noted that the inclusion of "microplastic" as a key word vastly increased the quantity of information obtained, as microplastics have attracted much research attention. Comparatively, our efforts to acquire relevant information on alternatives to microbeads led to few results, indicating a lack of research and attention on replacement products.

7 – Microbead Regulation in Canada and the United States

(Lead Author: Nicholas Girard)

7.1 Multi-Level Regulation of Chemicals in Canada

In Canada, every level of government plays role in protecting the public against risks from chemical substances: municipalities, the provinces and territories, and the federal government. Municipal governments are responsible for establishing, collection, recycling, and waste disposal programs, including managing municipal water supplies (Environment Canada, 2010b). Provincial governments enforce laws that govern the emission, transportation, use, and disposal of substances that may harm the environment (PollutionWatch, 2005) and develop and enforce all legislation pertaining to municipal and public water supplies (CWWA, 2012). Finally, the federal government leads in conducting scientific research on human and health issues, develops nation-wide legislation on chemical and environmental protection (Government of Canada, 2012b), and cooperates with the United States on joint chemicals management through initiatives such as the *Canada-United States Regulatory Cooperation Council on Chemical Management* (Government of Canada, 2011).

7.2 Canada's Federal Legislation for Regulating Chemicals

There are over 25 different laws covering the environment for which the federal government is responsible. In the present context, the 13 laws shown in **Table 2**, below, are the most pertinent.

Table 2 – Major federal laws covering environment and environmental health issues (adapted from Government of Canada, 2007).

<table>
<tr><th>Products</th><th>Emissions & Effluents</th><th>Habitat Protection, Land Use & Natural Resource Management</th></tr>
<tr><td colspan="2">Canadian Environmental Protection Act, 1999</td><td>Species at Risk Act</td></tr>
<tr><td>Pest Control Products Act</td><td colspan="2">Canadian Environmental Assessment Act, 2012</td></tr>
<tr><td>Food and Drugs Act</td><td>Arctic Waters Pollution Prevention Act</td><td>Canada Water Act</td></tr>
<tr><td>Transportation of Dangerous Goods Act, 1992</td><td>Fisheries Act</td><td>International Boundary Waters Treaty Act</td></tr>
<tr><td>Canada Consumer Products Act</td><td>Canada Shipping Act</td><td>Oceans Act</td></tr>
</table>

Three key federal laws that regulate the use of chemical substances in Canada include the (1) *Canadian Environmental Protection Act, (CEPA) 1999*, (2) *Pest Control Products Act (PCPA)*, and (3) *Fisheries Act*.

CEPA 1999 is one of Canada's most important laws in terms of pollution prevention, protecting human health and the environment (Environment Canada, 2010a). CEPA 1999 establishes the regulatory framework for the control of toxic substances. The Act addresses the manufacture, import, and use of toxic substances and is administered jointly by the Ministers of Environment and Health (CEPA, 1999). Following Royal Assent of CEPA 1999 in March 2000, Ministers of Environment Canada and Health Canada were tasked with categorizing 23,000 substances on the *Domestic Substances List* (DSL) by September 2006 to determine if they met the definition of "toxic" under CEPA 1999 (Department of Justice, 1999). The DSL are substances that were, between January 1, 1984, and December 31, 1986, manufactured in, imported into, or used in Canada on a commercial scale before comprehensive environmental laws were in place to assess their harm (Government of Canada 2007; 2010). The process of categorizing the DSL identified over 4,000 substances: 500 of which were considered high priorities, 2,600 medium priorities, and 1,200 low priority substances based on persistency, bioaccumulation, and inherently toxicity (PBiT), or present a significant human health exposure risk (Eaton, 2008; Lewis & Scott, 2014). The *Chemicals Management Plan* (CMP) is the framework behind this initiative.

7.2.1 Chemicals Management Plan

The CMP is a Government of Canada initiative aimed at monitoring, assessing, and regulating the effects of chemical substances by bringing all existing federal programs under one comprehensive strategy. There were a number of factors that prompted the Government of Canada to develop the CMP. There was an obligation from the federal government to address substances on the DSL (Department of Justice, 1999) and rising public concern on the potential harmful health effects of toxic chemicals and consumer product safety (Environmental Defense, 2011). While the CMP is made of various initiatives including those focused on monitoring, research, assessment, regulation and enforcement (Government of Canada, 2010b), one of the main CMP initiatives is to address the 500 high-priority substances. The objective of the CMP is to assess the 23,000 chemicals on the DSL by 2020. According to the CMP's latest progress report (fall 2015), roughly 2,740 substances have been assessed and 363 have been classified as toxic (Environment Canada, 2015b).

7.3 Progress on Banning Microbeads in the United States and Canada

7.3.1 United States

In 2014, seven states reviewed legislation on microbeads and on June 8, 2014, Illinois became the first jurisdiction in the world to impose a ban on microbeads in rinse-off cosmetics (Sierra Club, 2015; Perschbacher, 2016). The following year, 47 bills were introduced in 25 states of which nine were signed into law (Farquhar, 2015). **Figure 1**, below, shows the current state of affairs regarding State microbead legislation.

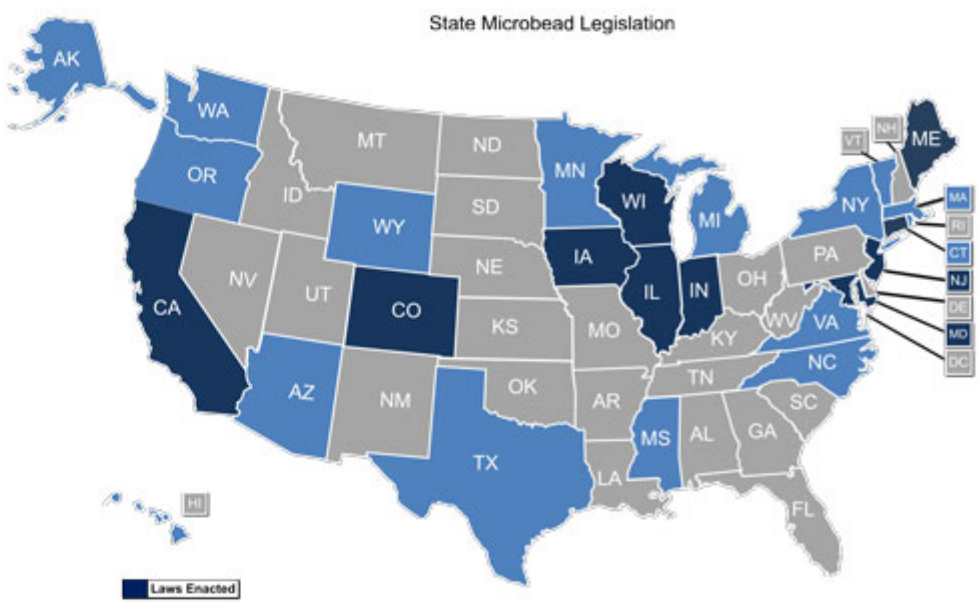

Figure 1: US State bans on microbeads as of October 2015 (Farquhar, 2015). The nine states coloured in dark blue have banned microbeads. The 16 states coloured in light blue have introduced bills into legislature.

Nine states, Colorado, Connecticut, Illinois, Indiana, Maine, Maryland, New Jersey, and Wisconsin, have banned the use of microbead in rinse-off cosmetic products. On October 8, 2015, California became the first jurisdiction to ban the use of biodegradable microbeads as a substitute product (Sierra Club, 2015). All state bans on manufacture of personal care products will be effective as of January 1, 2018, and sale of over-the-counter drugs (including, but not limited to: fluoride and whitening toothpaste, acne scrubs, and wrinkle creams) that contain microbeads will come into force as of January 1, 2020.

A Federal bill (H. R. 1321) entitled "The *Microbead-Free Waters Act of 2015"* was signed into law by President Obama on December 28, 2015, which bans rinse-off cosmetics that contain intentionally-added microbeads beginning on July 1, 2018, and will ban the manufacture of these products beginning on July 1, 2017 (White House, 2015). While the Environmental Protection Agency (EPA) has authority under the *Clean Water Act* to regulate microbeads from industry wastewater discharge, that authority does not extend to microbeads that are released from households (Copeland, 2015). Instead, the Food and Drug Administration (FDA) under the *Federal Food, Drugs, and Cosmetic Act* is the regulatory body responsible for enforcing the Microbead-Free Waters Act of 2015. This is noteworthy because in Canada, the sister organization of the EPA, Environment Canada (rather than the sister organization of the FDA, Health Canada) is the lead agency.

7.3.2 Canada

On March 24, 2015, the House of Commons unanimously voted for the government to take immediate action to add microbeads to the List of Toxic Substances under CEPA 1999. This resulted in the federal government expediting the review of microbeads under the CMP process (ECCC, 2016). According to CEPA 1999, "a substance is toxic if it is entering or may enter the environment in a quantity or concentration or under conditions that:

1. have or may have an immediate or long-term effect on the environment or its biological diversity;
2. constitute or may constitute a danger to the environment on which life depends or;
3. constitute or may constitute a danger in Canada to human life or health." (Department of Justice, 1999)."

When a substance meets these criteria, it is then referred as "CEPA toxic" (as opposed to "toxic" in a more colloquial sense).

At the June 22-23, 2015 meeting of the *Canadian Council of Ministers of the Environment*, ministers voiced their support for Environment Canada to conduct a scientific review of microbeads (ECCC, 2016). The scientific review carried out by ECCC (EC at the time) in July 2015, assessed the state of knowledge on microbeads and concluded that the persistency and continual release of microbeads in the environment might result in long-term effects on biological diversity and ecosystems, thus adhering to the definition of "toxic" outlined above in CEPA 1999 (Environment Canada, 2015a). It recommended adding microbeads to the List of Toxic Substances under CEPA 1999. On this basis, this would prohibit the manufacture, import, and sale of microbeads in all products (Environmental Defense, 2015). Two bills (C-680 and C-684) were tabled during the 41st session of parliament to amend the *Food and Drugs Act* and Part 7 of CEPA 1999, but they did not proceed prior to dissolution of Parliament and were subsequently dropped and replaced with what ECCC is currently proposing (ECCC, 2016).

On August 1, 2015, a proposed order to list microbeads in the List of Toxic Substances was published in Canada Gazette, Part 1, for a 60-day public comment period. A Notice of Intent was also published stating the Government of Canada's plan to propose regulations under CEPA 1999 to ban microbeads in personal care products used to exfoliate or cleanse (Government of Canada, 2015). Twenty-five industry associations and ten other stakeholder groups as well as over 200 individuals commented on the proposed regulation on a variety of topics including the definition of microbeads, harmonization with the U.S. *Microbead-Free Waters Act of 2015*, biodegradation, and alternatives (ECCC, 2016). The public consultation process was followed by a 30-day comment period closing on March 10, 2015. Comments received during this period will be taken under consideration while ECCC drafts the proposed regulations. According to ECCC's proposed regulation (2016), the federal ban would be implemented on the following dates:

- "December 31, 2017, prohibiting the manufacture and import of microbead-containing personal care products, including cosmetics, that are used to exfoliate or cleanse, excluding non-prescription drugs and natural health products;
- December 31, 2018, prohibiting the sale or offer for sale of microbead-containing personal care products, including cosmetics, that are used to exfoliate or cleanse, excluding non-prescription drugs and natural health products;
- December 31, 2018, prohibiting the manufacture and import of a microbead-containing non-prescription drug or natural health product that is used to exfoliate or cleanse; and
- December 31, 2019, prohibiting the sale or offer for sale of a microbead-containing non-prescription drug or natural health product that is used to exfoliate or cleanse".

At the provincial level, Ontario is currently the only jurisdiction in Canada proposing a ban on microbeads. On March 9, 2015, a private member introduced *Bill 75 – Microbead Elimination and Monitoring Act* to the Legislative Assembly of Ontario. The bill passed its second reading and has been referred to the Standing Committee on Finance and Economic Affairs. If the bill passes consideration, it will come into effect within two years and Ontario will become the first jurisdiction in Canada (including the federal government) to ban microbeads (Legislation Assembly of Ontario, 2015).

As indicated in the introduction, Loblaws and companies such as Johnson & Johnson and L'Oréal have committed to phase out microbeads from their products. These commercial self-regulatory activities are expected to continue even if the Canadian ban should not come to pass.

7.4 Policy Challenges for Microbead Regulation

7.4.1 Defining Microbeads

When microbeads were proposed for addition to Schedule 1 of CEPA in August 2015, they were defined as "synthetic polymers that, at the time of their manufacture, are greater than 0.1 μm and less than or equal to 5 mm in size" (Environment Canada, 2015a). Following consultations, the definition was narrowed to plastic microbeads between 0.5 μm in diameter to 2 mm in size (ECCC, 2016) over concerns voiced by industry that the existing definition covered a broad scope of plastics used as raw materials for consumer products (e.g. plastics bottles) by the plastics industry (ECCC, 2016).

According to some stakeholders, the proposed definition of microbeads creates a loophole that would allow for personal care products containing plastics to be sold that are over 2 mm in diameter or under 0.5 μm in diameter (i.e. nanoplastics) (Terry, 2015, ChemicalWatch, 2016; Ottawa Waterkeeper *et al*., 2016). This will require future attention, since nanoplastics possess similar qualities that make them harmful to the environment (UNEP, 2015b).

As *Microbead-Free Waters Act of 2015* defines microbeads more broadly as "any solid plastic particle that is less than five millimetres in size and is intended to be used to exfoliate or cleanse the human body or any part thereof" (White House, 2015). The Sierra Club of Canada (2016) expressed a concern that Canada could become a dumping ground for microbead-containing products banned in the United States.

7.4.2 Lag in Implementation Timelines

Timelines set out in the proposed Canadian regulation are six months behind timelines set out in the American federal act and other state jurisdictions for cosmetic and non-prescription drugs (Willis, 2016). The proposed timeline would result in products being banned in Canada six months after they are banned in the United States. From an implementation perspective, Ottawa WaterKeeper *et al*. (2016) argues this is problematic since it could make Canada a dumping ground (re: issues above) for products that can no longer be sold in the United States but that remain legal in Canada. The American federal law would also pre-empt state laws that have put forward more aggressive timelines to phase out microbeads from cosmetic and personal care products.

7.4.3 Biodegradability

Another challenge with several state and provincial microbead bills and laws has to do with biodegradability. Certain existing bills at the state and provincial level do either (1) not clearly define the term “biodegradable” or (2) permit the use of biodegradable microbeads. Ontario, for example, defines microbeads as “non-biodegradable solid plastic particles measuring less than one millimeter in diameter that are used in cosmetics, soaps or similar products as cleansing or exfoliating agents” in its Bill 75. Such definitions appear to allow manufacturers to replace synthetic plastic microbeads with another plastic “biodegradable” alternative (Perschbacher, 2016). This is a challenge, since studies suggest that biodegradable microplastics pose the same risks to aquatic life as conventional microbeads (Green *et al*., 2016).

The term “biodegradability” is also not applied in a standardized manner. According to Terry (2015), in certain bills, the term "biodegradable" is not defined (e.g. Illinois) and others are defined such that a microbead has to decompose in an industrial composting facility, often in high temperatures and controlled pH levels and do not meet the standard of biodegrading in an aquatic environment. On the other hand, Maryland has defined biodegradable as something that decomposes in a marine environment. Some commentators have noted this to be the biggest loophole in microbead legislations.

Both the U.S. *Microbead-Free Waters Act of 2015* and the proposed Canadian regulation will remove this conflict over biodegradability. The U.S. Act defines microbeads as “any solid plastic that is less than 5 mm in length” (White House, 2015) which removes the biodegradable loophole. A similar prohibition of biodegradable plastics as alternative products is also covered in the proposed Canadian regulation to match the U.S. law (ECCC, 2016). According to 5Gyres (2015b), the U.S. federal act will supersede state bills that include the “biodegradable loophole”, resulting in a stronger ban of microbeads. Assuming that the Canadian regulation will come to pass as planned, the loophole will also be fully closed in Canada by the end of 2019.

8 – Microbead Alternatives

(Lead Author: Acacia Paton-Young)

8.1 Current Natural Alternatives

The purpose of microbeads in various cleansers is to provide exfoliation. The small beads physically rub off dead skin or facilitate the cleaning of surfaces. Considering the new regulations for microbeads, some companies will need to use other ingredients to provide consumers with products that have the same exfoliation effects. However, cosmetic products that achieve similar exfoliation effects without the use of microbeads are *already* available on the market.

Before discussing the currently available alternatives, it is worth noting what some major relevant companies are doing. A good source of international company information is the *Beat the Microbead* Initiative (www.beatthemicrobead.org) lead by the Dutch non-government organization *Plastic Soup Foundation*. The industry section on the Beat the Microbead website showcases actions of a selection of international companies that have released statements in support of banning microbeads. The companies that were listed generally fit into three categories:

- Companies that never used microbeads in their products.
- Companies that will phase out microbeads.
- Companies that already switched to replacements.

Accordingly, the approaches used by the various companies to address consumer concerns are very diverse, as the following examples illustrate:

Unilever was the first company released a public statement in December 2012 agreeing to phase microbeads out of their products. Their target date was 2015 which, according to the Unilever website, has been met. All Unilever products are now free of microbeads. The alternatives used by this company are apricot kernels, cornmeal, ground pumice, silica, and walnut shells (Unilever, n.d.).

L'Oréal acknowledged in 2014 the difficulties associated with phasing out ingredients like microbeads. However, they are looking for suitable natural alternatives such as fruit seeds and minerals (L'Oréal, 2014).

Avon provided public statements agreeing to phase out microbeads (Plastic Soup Foundation, 2016). However, the direction in which they are going is less clear. According to their website, they will phase microbeads out of their products once they have looked at suitable alternatives (Avon, n.d.).

Johnson & Johnson has found microbead alternatives, but their statement on microbeads did not include what the alternatives were (Johnson & Johnson, 2016). However, according to an article by *5Gyres* on ecowatch.com, Johnson & Johnson were lobbying states to alter the definition of biodegradable (5Gyres, 2015a).

Not only do company strategies differ, alternative products can achieve exfoliation in variety of completely different ways. Using the categories described by the blog *Eminence*, there are four categories of alternatives that can be distinguished (Pike, 2015):

- Physical exfoliants: physically scrub off dead skin. Like almond shells, etc.
- Enzyme exfoliants: help dissolve the dead skin on the surface
- Chemical exfoliants: use acids like BHA and AHA to remove dead skin at a deeper level
- Cream exfoliants: mixture of physical and natural acids to exfoliate

While it is not possible to summarize the most important alternative products with any measure of certainty—because much of the relevant information remains undisclosed—there are examples to illustrate the breath of diversity. **Table 3**, below, provides examples from the four categories based on the information available on two blogs sites.

Table 3 – Sample alternative exfoliants according to the blogs *Total Beauty* and *Allure*.

Product Name	Alternative Ingredients	Exfoliant Category	Source
Bioré	Synthetic and microcrystalline wax beads.	Physical	Products listed in a post on *Total Beauty* (McCarthy, 2014)
Elemis	Jojoba esters	Physical	
Microdelivery peel	Lactic and salicylic acid		
Skin Medica	Alpha and beta hydroxyl acids	Chemical	
Murad Age Reform, AHA/BHA Exfoliating Cleanser	Glycolic acid	Chemical	
Jan Marini	Papaya enzyme	Enzyme	
Arcona cranberry gomageexfoliant	Volcanic minerals	Physical	
Algenist triple action micropolish	Alguronic acid, glycolic acid	Chemical	
St. Ives even and Bright Pink Lemon and Mandarin	Apricot pits, walnut shells, kernel meal	Physical	Product listed in a post on *Allure* (Colameo, 2014).
Yes to Coconut polishing body scrub	Coconut husk powder	Physical	
Frank Cacao Coffee Scrub	Cacao, coffee beans, brown sugar, sea salt, walnut shells	Physical	
Forbidden Rice Body Scrub	Black Rice, Lotus Leaf, beans	Physical	
Kora organics exfoliating cream	Oat flour and bamboo	Cream	

Each of these products, arguably, would require a risk assessment to fully understand the potential consequences of these products in aqueous environments. Despite significant research using multiple keyword combinations and sources, no academic literature on the potential risks of these microbead alternatives was found.

Media sources provide some limited commentary on the potential risks of natural alternatives. *Cosmetics Design* (Yeomans, 2014) interviewed Greg Boyer who is Chair of the chemistry department at SUNY College of Environmental Science and Forestry. His concerns were that the natural exfoliants could present problems that are different from microbeads. Specifically, he talked about bacteria degrading sugars for energy. In stratified water columns, there may not be enough oxygen to support the degradation process, and fish and other marine-life could die as a result because there would not be enough oxygen to sustain them.

Stiv Wilson, Associate Director of the non-government organization *5Gyres*, provided a more optimistic view in an interview with the British newspaper *The Guardian*. Wilson stated that the biodegradability is what makes these alternatives better as long as these alternatives are sourced sustainably. The relative impact of sustainably produced natural biodegradable alternatives will be relatively lower than that of microbeads (DuFault, 2014).

Building on concerns of potential new and different problems associated with microbeads, The Guardian also interviewed Victoria Fantauzzi—the co-founder of *La Bella Figura Beauty*. Fantuzzi's concerns were focused on a potentially problematic supply chain. She used the example of Mexico where families lost their farms because their products were outsourced to different, cheaper growers (DuFault, 2014). The Mexican farmers were unable to compete with companies that came in and produced 'cheap crops using cheap labor and GMO seeds,' (DuFault, 2014).

Adapting to microbead-free products will be easier for consumers than for businesses because the currently available alternatives are of high quality, according to the *Huffington Post* (Adams, 2014). According to the article, consumers like microbeads because they are inert exfoliants that do not cause adverse skin reactions and companies approve of microbeads because they are easier and cheaper to produce (Adams, 2014). According to New York based dermatologist Dr. Buka, the alternatives that are available are just as effective as microbeads. The ready availability of alternatives in the market will make the switch easier for consumers, according to Dr. Jailman. Dr. Jailman is a New York based dermatologist and author of *Skin Rules: Trade Secrets from a Top New York Dermatologist.* However, according to Dr. Buka, companies will have to use more expensive ingredients and may have a harder time adjusting (Adams, 2014). However, as mentioned above, not all companies have to adjust their products because not all products contain microbeads.

8.2 Potential Synthetic Alternative

Polyhydroxyalkanoate (PHA) is a linear polyester developed by a fermentation process using bacteria. Companies believe the biodegradable properties of PHA make it a suitable alternative for microbeads in cosmetics. PHAs are biodegradable in both aerobic and anaerobic environments. PHA transforms into mostly carbon dioxide and water (in aerobic environments where oxygen is available) or water and methane (in anaerobic environments) within a reasonable time frame (Voinova, Gladyshev, & Tatiana, 2008).

Some suppliers are ready to provide PHA microbeads to cosmetic companies. An example of a company involved in the development of PHA microbeads is TerraVerdae Bioworks. This company has developed and promoted their product as biodegradable, non-GMO, and non-toxic alternative to plastic microbeads (Business Wire, 2015). TerraVerdae Bioworks has facilities in Canada and the UK and a mission "to transform the global plastics industry by providing sustainably produced, biodegradable alternatives to petroleum-based materials." William Bardosh, its CEO and founder, states that their product rapidly breaks down to carbon dioxide and water in marine environments, leaving no harmful solids—that the product is "intrinsically biodegradable" (Business Wire, 2015). For instance, the product meets the *American Society for Testing and Materials* Industry Standards for Biodegradation in a Marine Environment (Business Wire, 2015). Bardosh raised concerns that the new microbead legislation would prohibit PHA (because of the broad definition of "microbead") despite the potential for it to act as an environmentally friendly alternative to current non-biodegradable microbeads (Forman, 2016). It is worth noting that the biodegradable plastics developed by TerraVerdae Bioworks has applications in other fields (not cosmetics) and markets. Bardosh believes TerraVerdae's PHA-based microbead will have a place in the markets in Europe and Asia, and PHAs will be used in applications such as cleaners to remove grease and 3D printing (Forman, 2016).

Another supplier of PHA microspheres comes from an alliance between Metabolix Inc (an advanced biomaterial company) and the cosmetics branch of Honeywell. Their product is a biodegradable microbead called Mirel Micropowder (Laird, 2015). According to their website, they are currently working on PHA technology to replace microbeads. Their product degrades naturally and quickly in both salt water and fresh water environments. Additionally, Mirel Micropowder will degrade in waste water treatment systems (Metabolix, n.d.).

Aside from the promotional information provided by cosmetic companies, data on PHAs in cosmetics is minimal. PHA does not show up as an ingredient in the cosmetics surveyed for this literature search. One student presentation at an Undergraduate Engineering Conference at the University of Pittsburgh concludes that PHA is a suitable alternative and its biodegradable properties make it the best option (Celmo & Addison, 2015). It is not clear how well founded this judgment is.

Concerns about the potential for biodegradable microbeads to be harmful led California to ban them. As indicated above, the *Microbead-Free Water's Act of 2015 also* bans rinse-off cosmetics that contain intentionally-added microbeads—including biodegradable plastic microbeads. According to an article in *The Guardian* (O'Connor) it is unclear if the biodegradable alternatives will introduce harmful chemicals into the waterways because they may still absorb toxins in the water and introduce them into the food chain (O'Connor, 2015). Additionally, the article discussed concerns about the lack of standards. For example, companies are able to label something as biodegradable without a relevant certificate (O'Connor, 2015).

A ban on *all* "biodegradable" plastics may be overly sweeping because the meaning of the term is very ambiguous. It appears that some plastics labelled as biodegradable will *not* transform in marine environments (they require the high temperatures provided by commercial composting facilities) while other *do* transform in marine environments. Persistence is a major component of an environmental risk assessment and it would be interesting to speculate on the consequences of the arguably sweeping prohibition within the new US regulation and the proposed Canadian law that limit incentives to innovation of new "intrinsically" biodegradable plastics (of any type, not just microbeads).

9 – Microbeads: Tip of the “Toxic Plastic-berg”?

(Lead Author: Simon Lester)

9.1 Microbeads in the Context of Global Plastic Production

Plastics have many desirable properties that make them extremely versatile materials. Inexpensive, durable and lightweight, they have revolutionized the modern world (Andrady & Neal, 2009). Plastics are used for a staggering variety of products and it is challenging to imagine a world without them (Andrady & Neal, 2009). Due to this versatility, annual global plastic production has grown from roughly 5 tonnes in the 1950's (Bergmann, Gutow, & Klages, 2015) to 300 million tonnes globally (PlasticsEurope, 2015b). Plastics are used in nearly every consumer product, and forecasts indicate that production of plastics will continue to increase by about 1 percent a year (PlasticsEurope, 2015a). All plastics have the potential to transform into “secondary” microplastics over time, however, the time span required depends on the nature of the plastic and the environmental conditions.

“Primary” microplastics in the form of microbeads were introduced in the 1960's and their use in consumer products increased significantly in the 1990's (IJC, 2016a). These plastics are considered "primary" microplastics because they are manufactured to be small in size; they function as abrasives in personal hygiene and cosmetic products. While no specific estimate of the quantity of microbeads produced has been found, a very conservative estimate for total microbead production, assuming that the global population uses as many microbeads as the average American citizen (unlikely), indicates microbeads to account for less than 1/10,000 of global plastics production.

Nevertheless, the scale of microbead production is not trivial. In the United States alone, an estimated 263 tonnes of primary microplastic are discharged per year (Napper *et al.* 2015). This would fill approximately 3000 bathtubs, and could contain as many as 18 trillion microbeads.

Five major gyres are present on Earth, two in the Pacific Ocean, two in the Atlantic Ocean and one in the Indian Ocean. These ocean gyres have high concentrations of marine debris, much of which is plastic (Thompson *et al.* 2004). Microplastics account for approximately 25 percent of the total mass of plastic debris estimated to be present in the North Atlantic subtropical gyre (Gouin *et al.* 2011). The appropriately named "5Gyers" organization draws media attention to the plastics pollution problem in these areas. While the gyres have been popularized with sensational names such as the 'Great Pacific Garbage Patch' (Kaiser, 2010), these names are misleading. They imply an image of a large mat of floating plastic debris in the oceans, while in reality these areas are primarily contaminated with barely visible microplastics; not the large mat of floating plastic debris twice the size of Texas, as is frequently implied (Kaiser, 2010).

Thompson's (2004) publication, "*Lost at Sea: Where is all the plastic?*" drew attention to the need to research the life-cycle of the plastic production industry, as plastic debris has become one of the most abundant and observable pollutions globally. It is now estimated that 10 percent of all plastics globally, either through mismanagement or littering, end up in the environment (Cole *et al.* 2011). To help illustrate the scale of the microbeads vs. macroplastics issue, it is noted that the amount of mismanaged macroplastics, primarily from land based sources in the United States is 1000 times larger than the estimated quantity of discharged microbeads, at an estimated 280,000 tonnes (Jambeck *et al*., 2015). We have to remember, however, that these mismanaged plastics remain mostly in their macroscopic state after entering the environment, but once in the oceans, plastics eventually fragment into small pieces, known as secondary microplastic (Andrady, 2011; Barnes *et al*., 2009; Thompson *et al*., 2004). Microplastics of both types are now thought to be found in all marine environments, from deep ocean sediments (Woodall *et al*., 2014) to ice in the poles (Barnes *et al*., 2009).

The durable nature of plastics causes plastic to accumulate in the environment over long periods of time (Ryan *et al.*, 2009). Exemplifying this idea, Barnes *et al.* (2009) claim that every bit of plastic ever manufactured, with the exception of that which has been incinerated, still exists. A recent discovery puts a twist on this statement, however. Researchers have found that some microbes are capable of metabolizing plastics, opening an entirely new field of study and potential mechanism for decomposition of plastic debris (Yang *et al.* 2014; Yoshida *et al*., 2016).

While plastics play an increasingly important role in modern societies (Andrady & Neal, 2009), the environmental consequence resulting from plastics entering the environment is a serious challenge requiring immediate response according to Roy, *et al.* (2011).

Accordingly, oceans researchers have made an array of recommendations regarding plastic waste. These recommendations are focused on improved management of waste through infrastructure upgrades (IEEP, 2013; UNEP, 2014b) and improved recycling programs (Hopewell, Dvorak, & Kosior, 2009), as well as by changes in consumer and producer behaviours (Bergmann, Gutow, & Klages, 2015). Jurisdictions around the world have imposed bans on some plastic products, such as shopping bags (IEEP, 2013), and debates are beginning to focus on plastic bottle bans (Banerjee, 2016). In one case, researchers have called for *all plastic waste* to be defined as hazardous to encourage better management practices (Browne, 2013).

9.2 Past, Current and Future Research Directions in Plastic Pollution Research

9.2.1 Wildlife

Plastic pollution research initially focused on wildlife mortalities resulting from entanglement in lost fishing gear, plastic bags and packaging, or ingestion of floating plastic debris (Laist, 1987). The negative effects, including mortalities from large plastic parts, are well documented (Browne, 2013; GESAMP, 2015; IEEP, 2013; Laist, 1987; Thompson *et al.,* 2011b; UNEP, 2014b). The persistence of plastic debris has been clearly "illustrated by accounts that plastic swallowed by an albatross had originated from a plane shot down 60 years previously, some 9600km away" (Barnes *et al*., 2009, p. 1986). There is a lot of consensus among experts on the direct negative impacts of larger plastics in the ocean which has led to the need to study their complete life-cycle.

Research on the impacts of microplastics on wildlife is relatively new. The understanding of risk remains in the hazard characterization stage of evaluation (GESAMP, 2015). It has been documented that wildlife of all sizes in the environment encounter and ingest microplastic debris (Gall & Thompson, 2015), but the effect of this ingestion remains uncertain. Microplastics can be contaminated with harmful chemicals, either absorbed from the environment or incorporated at the time of manufacture and are capable of desorbing into marine organisms after ingestion (Cole *et al*., 2011; Ivar Do Sul & Costa, 2014). While early research indicates that ingestion of microplastics by marine organisms can have sub-lethal effects in individuals, effects on populations are unknown (Gall & Thompson, 2015). The role of microplastic ingestion in bioaccumulation—an important concern in pollution research—is thought to be minimal (Koelmans, *2015;* Napper *et al*., 2015). There is also little certainty regarding the indirect effects that may be attributable to microplastics. Plastic debris may function as a distribution mechanism for invasive species that hitchhike on plastic debris, but the impacts of plastic on microbial life are poorly understood (Zettler *et al.,* 2013).

9.2.2 Environmental Fate in Aquatic Environments

During the last ten years, research focus shifted onto sources, quantities, and the ultimate environmental fate of plastic debris in the environment (Andrady, 2011; Barnes *et al*., 2009). Larger plastic debris was found to be degrading into microplastics that are now found in high concentrations in the environment. As a consequence, research attention shifted to microplastic impacts in both marine and freshwater ecosystems, and on human health (Cole *et al*., 2011; Ryan *et al*., 2009). Studies began to quantify the amount of plastic debris entering the environment and how these plastics are degraded into microplastics (Barnes *et al*., 2009; Cole *et al*., 2011; Ryan *et al*., 2009; Thompson *et al*., 2004; Thompson *et al*., 2005). This research has begun to develop a body of evidence for negative effects caused by microplastics.

Sources of plastics into the environment are thought to come from those countries with the weakest waste management infrastructures and highest populations (Jambeck *et al*., 2015). However, due to inconsistency between jurisdictional waste management definitions (Barnes *et al*., 2009; Ivar Do SulCosta, 2014) and challenges identifying marine plastic debris, no exact estimates of plastic release into the ocean exist. Plastic waste inputs into the marine environment are estimated to average around 10 percent of total plastic production globally (Cole *et al*., 2011), however, high degrees of regional variation are thought to exist (Jambeck *et al*., 2015).

The mechanisms that cause plastics to degrade and fragment into microplastics are relatively well understood. Key mechanism are wave action (especially on shorelines) and exposure to ultra violet light (Barnes *et al*., 2009). However, rates of degradation of plastic in the environment are still largely unknown (Law & Thompson, 2014).

Furthermore, quantification of microplastics in *freshwater* environments are less studied than in marine environments, though similar negative impacts are thought to exist between marine and freshwater environments (Eerkes-Medrano, Thompson, & Aldridge, 2015). Some research quantifying microplastics in fresh water ecosystems has been performed globally (Driedger *et al.*, 2015). The Great Lakes of North America are observed to have high concentrations of microplastics in their surface waters. Due to close proximity to areas of high population density, it is speculated that higher concentrations of primary microplastics, like microbeads, are found in the Great Lakes than in the marine environment (Driedger*et al*., 2015; Eriksen*et al*., 2013).The United Nations Environmental Program has identified that freshwater and terrestrial ecosystems are largely unstudied (Eerkes-Medrano, Thompson, & Aldridge, 2015; Rillig, 2012) and research in now focusing on these ecosystems, with particular attention paid to human health effects.

9.2.3 Human Health Impacts

Humans are exposed to microplastics either directly from the drinking of freshwater, or indirectly from eating seafood. While it is evident that the potential exists for human health effects, this area is a major knowledge gap (Government of Canada, 2015) and requires more research (GESAMP, 2015), particularly for freshwater systems as most research has focused on marine environments (Eerkes-Medrano, Thompson, & Aldridge, 2015). More research is needed, and consistent definitions, sampling methodologies and definitions of best practices will allow for better comparison of results (Arthur, Baker, & Bamford, 2009).

9.2.4 "Biodegradable" Materials

The increased development and production of biodegradable plastics has led to research into their environmental fate and potential human health effects (Green *et al*., 2016; 2015; Thompson *et al.,* 2009a; Thompson *et al*., 2005; Wright, Thompson, & Galloway, 2013). Much debate surrounds the degree to which "biodegradable plastics" do, in fact, degrade, especially when introduced into the natural environment where conditions vary widely (UNEP, 2015a).

Biodegradation is not a simple process. Multiple mechanisms and processes, such as composting, oxi-degradation, and photo-degradation, exist. They each define a similar outcome, but represent fundamentally different mechanisms of degradation. For example, plastics labelled as compostable may not, as is commonly perceived, biodegrade in the natural environment because special environmental conditions only found in industrial composters are needed (Roy *et al*., 2011).

A complete evaluation of the many processes by which biodegradable plastics are degraded is beyond the scope of this paper, however, it should be noted that there are many unanswered questions regarding the ultimate fate of biodegradable plastics (Ren, 2003; Roy *et al*., 2011).

9.3 Policy Challenges for Secondary Microplastics Pollution

In contrast to primary microplastics (such as microbeads), secondary microplastics pose a different set of policy challenges. Microbeads can be managed through regulations on their manufacture, involving relatively few and clearly identifiable stakeholders. Additionally, they can be regulated nation by nation, with relatively little consequence for industry. Secondary microplastics are created through the mismanagement of *any* plastic produced or used internationally, which comprises the contributions of many stakeholders. They arise from global sources of pollution, the social benefits of their source (plastic products) is undisputed, replacement products may not exist, and enforcement in a global common such as the oceans is very difficult. These fundamental differences complicate the policy environment for the problem (Shaxson, 2009).

Therefore, the development of policies to address global marine microplastic pollution will be challenging. Many stakeholders and governments are required to participate, and knowledge gaps in health effects and environmental impacts coupled with high degrees of uncertainty further complicate the problem. The environmental fate is hard to track, as waste is deposited primarily on land, (Jambeck *et al*., 2015) and then plastics migrate into international waters where jurisdictions and responsibilities are difficult to establish. Furthermore, plastics play an important and increasing role in modern society (Thompson *et al*., 2009b), and any new policies regarding plastics must fully consider the implication on the societal benefits obtained from plastics (Andrady & Neal, 2009).

Despite recent calls from the public for regulations banning the production of plastic products, such as microbeads (5Gyres, 2016), plastics bags (IEEP, 2013) and bottles (Banerjee, 2016), academic literature primarily focuses on two strategies to curb plastic waste entering the environment: waste management systems and increasing recycling efforts (Hopewell *et al*., 2009; UNEP, 2009, 2014c; STAP, 2011; IEEP, 2013; GESAMP, 2015).

Some scholars (e.g., Browne, 2013) have even proposed that *all* plastic waste should be classified as “hazardous”. This proposition is based on concerns over the accumulation of plastic waste in the environment, associated environmental and health concerns, and the lack of progress in preventing plastic waste from entering the environment. While this may seem an extreme position, the fact that many jurisdictions now consider plastic *microbeads* to be “hazardous” or “toxic” is a step toward this broader concern: microbeads may in fact just be the tip of a “toxic plastic-berg.”

10 – Discussion

The acknowledgement that microbeads must be treated as “toxic” represents a growing understanding of the environmental impacts of microplastics. This understanding does not come directly from studying microbeads, but from the growing scientific consensus that all microplastics (both primary and secondary) are accumulating and are harmful to the environment. While the regulation of microbeads in personal care products is an important step, it will not solve the global microplastics pollution problem.

Considering the key benefits society derives from now ubiquitous plastics, the banning of all plastic products is inconceivable. However, societies could do much more to prevent plastic wastes from entering the environment. The associated problems may still be hidden in the oceans, but the fact that plastics do not chemically decompose means that they basically “are forever” (to borrow a slogan from the diamond industry). They may become split into smaller units, but this conversion of large plastic pieces into microplastics is *not* an environmental benefit. Dilution is not the solution to pollution and decreasing the size of plastics is even less helpful.

Social change seems necessary to manage how we view end-of-life plastics. There is a need to think of these not at waste, but as recyclable feedstock for the manufacture of new plastic products (World Economic Forum, 2016). While many of the problems that are present with existing plastics economies can be addressed by the classic "3 R's" of reduce, reuse, recycle, there is a movement to include more "R's" to the list. These include "rethink", "refuse" and "rot" resulting in at least “6 R’s” (pRRRdy.com, 2016, Sustainable World Coalition, 2016).

The redesign of entire systems of production that focus on cradle-to-cradle or complete life-cycles of materials may require rethinking our consumption habits. Many biodegradable and compostable plastics, while developed to address plastic pollution, have been shown to have a similar environmental fate to conventional plastics. We will have to see if some biodegradables are indeed “intrinsically biodegradable” (that is, that they will degrade in most natural environment without human interference in relatively short time).

Some products, such as those with microbeads, fit into the "refuse" category of the "6 R's". If more products are understood by society as environmentally damaging within their entire life-cycle, they we may see decreasing demand. One mechanism is the *Plastics Disclosure Project*, through which business publish their plastic use. It allows for consumers to choose products that are less plastic intensive and investors to understand risk exposure to increasing plastics regulation (The Plastic Disclosure Project, 2014; UNEP, 2014c). New and creative solutions focused on solving the plastic pollution problem will likely start to span many of the "R" categories, and the development of new products like edible, inexpensive eating utensils (Munir, 2016) may become more commonplace in the future.

Solutions for preventing microplastic pollution will need to include improved waste management and sewage treatment infrastructures. New technologies (such as nanomaterials) and new ideas may bring practical and affordable solutions (Newport, 2016). Advances in biotechnology and the use of biologicals in the treatment of plastic waste provide another possible avenue for the future (Yang *et al.*, 2014; Yoshida *et al*., 2016). All these efforts in diagnosis, design and therapy need to be global. It is hard to conceive of practical solutions that do not take into account the important discharges of plastics into the ocean from Asia, for example (Jambeck *et al*., 2015).

Plastic waste will likely remain a complex, maybe even wicked policy problem. At the same time, at least one commentator characterized the plastic problem as comparable to the issue of climate change (Glazner, 2015). However difficult, the benefits of preventing plastic waste from accumulating in the environment will almost certainly justify the prevention efforts. While it is unthinkable to imagine a modern world without plastics, there is a certainly a growing understanding that plastics must be managed intelligently. The important first step will be to understand and globally communicate the scale of the issue. The debate over microbeads has opened the door a crack to now attempt such and ambitions international research, communication, and policy project.

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