



Review

International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): A review



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ABSTRACT

Marine plastic pollution has been a growing concern for decades. Single-use plastics (plastic bags and microbeads) are a significant source of this pollution. Although research outlining environmental, social, and economic impacts of marine plastic pollution is growing, few studies have examined policy and legislative tools to reduce plastic pollution, particularly single-use plastics (plastic bags and microbeads). This paper reviews current international market-based strategies and policies to reduce plastic bags and microbeads. While policies to reduce microbeads began in 2014, interventions for plastic bags began much earlier in 1991. However, few studies have documented or measured the effectiveness of these reduction strategies. Recommendations to further reduce single-use plastic marine pollution include: (i) research to evaluate effectiveness of bans and levies to ensure policies are having positive impacts on marine environments; and (ii) education and outreach to reduce consumption of plastic bags and microbeads at source.

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Contents

1.	Introduction	17
1.1.	Microplastics vs macroplastics.	18
1.2.	Evidence of impacts	18
1.3.	Microbeads in cosmetics	18
1.4.	International strategies to reduce plastic marine debris	18
2.	Methodology and approach	19
3.	Results and discussion	19
3.1.	Plastic bag policies	19
3.2.	Microbead policies	21
3.3.	Effectiveness of policies to reduce single-use plastics	21
4.	Conclusions	24
	Acknowledgements	24
	References	24

1. Introduction

Plastics are now ubiquitous in the marine environment, and urgent action is required to mitigate this worsening trend (Rios et al., 2007; Rochman et al., 2015b). In 2010, an estimated 4.8–12.7 Mt of plastics entered the oceans globally (Jambeck et al., 2015). A 2014 study (from six years of research by the 5 Gyres Institute) estimated that 5.25 trillion

plastic particles (weighing 269,000 tons) are floating in the sea. Although the contribution of plastics in man-made garbage is roughly 10% by mass (Barnes et al., 2009), it is estimated that plastic debris accounts for 60–80% of marine litter (Derraik, 2002), reaching 90–95% in some areas (Walker et al., 1997, 2006; Surhoff and Scholz-Böttcher, 2016). Due to its durability, the lifespan of plastic is estimated to be hundreds to thousands of years (Wang et al., 2016). In 2014, UNEP announced concern over the threat of widespread plastic waste to marine life.

Plastics have been reported as a problem in the marine environment since the 1970s (Carpenter and Smith, 1972; Colton et al., 1974). However, only recently has the issue of plastic pollution in marine and

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freshwater environments been identified as a global problem (Andrady, 2011; Eriksen et al., 2013; Vegter et al., 2014; Eerkes-Medrano et al., 2015; Perkins, 2015). Consequently, marine plastic pollution has become a significant environmental concern for governments, scientists, non-governmental organizations, and members of the public worldwide (Seltenrich, 2015). Entanglement of species by marine debris can cause starvation, suffocation, laceration, infection, reduced reproductive success and mortality (Katsanevakis, 2008; Baulch and Perry, 2014; UNEP and NOAA, 2015). Previous studies focused on entanglement of marine mammals and other species in net fragment litter or 'ghost fishing gear' (Walker and Taylor, 1996; Laist, 1997; Clapham et al., 1999; Bullimore et al., 2001; Eriksson and Burton, 2003). For example, Antarctic fur seals are commonly entangled in plastic marine debris (Walker et al., 1997; Waluda and Staniland, 2013). Ingestion of plastics by birds (Moser and Lee, 1992; Robards et al., 1997; Cadée, 2002; Mallory, 2008) and turtles (Mascarenhas et al., 2004; Bugoni et al., 2001; Tomas et al., 2002) have also been widely reported. Plastic bags have been identified, among macroplastic litter items, most harmful to marine biota (Besseling et al., 2015; Hardesty et al., 2015), but can also have impacts beyond marine species.

The existence of plastics in the marine environment presents a number of challenges that hinder economic development. Stranded plastic along shorelines creates an aesthetic issue, which has negative impacts for tourism (Jang et al., 2014). Economic losses are associated with reduced tourism revenues, negative impacts on recreational activities, vessel damage, impairment in marine environments, invasive species transport and damage to public health (Hardesty et al., 2015). Stranded shoreline plastic also negatively impacts shipping, energy production, fishing and aquaculture resources (Cole et al., 2011; Sivan, 2011). A conservative estimate of the overall economic impact of plastics to marine ecosystems is ~\$13 billion US/year (Raynaud, 2014), although the true environmental costs are difficult to monetarize. However, reported impacts of marine plastic debris on marine life include nearly 700 species, from tiny zooplankton to the largest 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 (Gall and Thompson, 2015).

1.1. Microplastics vs macroplastics

Plastics are comprised of microplastics (first coined by Thompson et al. (2004)) and macroplastics. Macroplastics (>5 mm) enter the marine environment via dumping or poor waste management (Pettipas et al., 2016). Over the past decade, growing efforts have been made to monitor impacts of microplastics in the marine environment (Seltenrich, 2015). National Oceanic and Atmospheric Administration (NOAA) define microplastics as fragments <5 mm in diameter (Barboza and Gimenez, 2015), with some researchers using <1 mm diameter as the threshold (Goldstein et al., 2012). Microplastics comprise: primary microplastics (e.g., microbeads), and secondary microplastics, from degraded macroplastics (e.g., plastic bags) (Ivar do Sul and Costa, 2014; UNEP, 2015, 2016; Napper et al., 2015). The annual global production of plastic is ~300 million tonnes (Napper et al., 2015), with roughly 50% disposed of after a single-use (Mathalon and Hill, 2014). Established empirical data suggest that large pieces of plastic (macroplastics) can cause significant harm in the marine environment through entanglement (Rios et al., 2007). Recent studies suggest that risks of microplastics (including degraded macroplastics, microbeads and microplastic fibres) in the marine environment may pose more of a threat than macroplastics (Browne et al., 2011; Desforges et al., 2014; Thompson, 2015), but research and policies to reduce pollution from these sources are lacking.

1.2. Evidence of impacts

Microplastics in the marine environment can travel vast distances floating in seawater, or sediment to the seabed (UNEP, 2015). The five

plastic gyres established throughout the oceans are well documented, particularly the "Great Pacific Garbage Patch" (Goldstein et al., 2012). Accumulation in these gyres is exacerbated because plastics take centuries to degrade (Cole et al., 2011). In addition to floating and stranded plastic debris, the deep sea is possibly the largest global marine litter depository (Pham, 2014; Tubau et al., 2015).

Large plastic items, such as discarded fishing rope and nets, can cause entanglement of invertebrates, birds, mammals, and turtles (Harper and Fowler, 1987; Walker and Taylor, 1996; Laist, 1997; Eerkes-Medrano et al., 2015) but marine environment is also contaminated with much smaller microplastic particles. These have been reported at the sea surface (Law and Thompson, 2014), stranded on shorelines (Claessens et al., 2011), and on the seabed (Van Cauwenberghe et al., 2015; Tubau et al., 2015). Microbeads are commonly white or opaque in colour, and research has found microbeads to be commonly mistaken for plankton by many surface feeding fish species. Ingestion of plastics by aquatic organisms is one of the major deleterious environmental impacts in the marine environment (Baulch and Perry, 2014; UNEP, 2016). Due to their small size and presence in pelagic and benthic ecosystems, contaminants associated with microplastics are potentially bioavailable for many organisms (Barboza and Gimenez, 2015). Persistent organic pollutants sorbed onto microplastics can accumulate at concentrations several orders of magnitude higher than in ambient seawater (Andrady, 2011). A growing concern related to microplastics is that they can also enter the human food chain through ingestion of fish, shellfish and filter feeders (Mathalon and Hill, 2014; Chang, 2015), causing potential human health impacts (UNEP, 2015; GESAMP, 2016). Filter-feeding mussels have been reported to contain microplastics in their tissues (Besseling et al., 2015; Mathalon and Hill, 2014), but the toxicological risks are poorly understood and represents an important challenge for future research (Goldstein et al., 2012; Seltenrich, 2015; Miranda and de Carvalho-Souza, 2016).

1.3. Microbeads in cosmetics

Microbeads have increasingly been manufactured (to replace natural exfoliating materials, including pumice, oatmeal, and walnut husks) for single-use cosmetics, such as abrasive exfoliating cleansers and toothpastes (Chang, 2015). Recent studies reported that some cosmetic products contain approximately as much plastic by weight as there are in the plastic container packaging (UNEP, 2015). Microbeads are designed to be disposed of via wastewater treatment infrastructure. However, wastewater treatment facilities are not designed to remove manufactured microplastic particles, which means that these are currently released into aquatic ecosystems. An estimated 8 trillion microbeads are released into aquatic environments daily via wastewater treatment plants (Rochman et al., 2015a).

1.4. International strategies to reduce plastic marine debris

Governments have struggled for decades to reduce marine plastic debris (Rochman et al., 2015a). The International Convention for the Prevention of Pollution From Ships (MARPOL 73/78) was signed in 1973, although a complete ban on the disposal of plastics at sea was not enacted until 1988. Even though 134 countries agreed to eliminate plastics disposal at sea, research has shown that the problem of marine debris has worsened since MARPOL 73/78 was signed. This may be because the marine debris problem is related to incorrect disposal of waste on land.

Many non-governmental organizations (NGOs) conduct monitoring research on marine debris to increase awareness (Pettipas et al., 2016). For example, The 5 Gyres Institute and the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection engage in awareness campaigns. The Ocean Conservancy oversees the International Coastal Cleanup (ICC). The ICC encourages other NGOs and volunteer

groups to engage in mitigating marine debris by cleaning up coastal areas across the globe. The Honolulu Strategy outlines strategies for prevention and management of marine debris. (UNEP and NOAA, 2015). The Honolulu Strategy has been adapted across the globe to meet the specific needs of different regions, such as Canada and the U.S. (Pettipas et al., 2016). Two strategies from the Honolulu Strategy are of particular interest. One focuses on market-based instruments (e.g., levies on new plastic bags) for minimizing waste. A second strategy creates policies, regulations, and legislation to reduce marine debris (e.g., imposing bans on microbeads and/or plastic bag production).

2. Methodology and approach

Impacts of macroplastics are well documented in the literature, but few studies examine policies related to mitigating single-use plastics (plastic bags and microbeads) in the marine environment. The lack of global policy studies aimed at mitigating single-use plastics accumulating in the marine environment was the driver for this study. This study reviewed current trends of international management practices related to market-based strategies and policies for banning or adding levies on single-use plastics (plastic bags and microbeads), not previously described in the academic literature.

To address limitations and issues associated with single-use marine plastic pollution (both plastic bags and microbeads), a systematic literature review of peer-reviewed and grey literature, as well as NGO websites, was conducted to assess current policies. Searches using ProQuest, Science Direct, Web of Science and Google Scholar were conducted. Search terms included, “microbeads” “plastic bags” “single-use plastic” “national policies” “legislation”. Results describing policies, legislation, bans or laws related to plastic bags or microbeads were included in this review. Based on these results, recommendations to support current and future policies on global microbeads and plastic bag management strategies, and areas for future research were identified.

3. Results and discussion

3.1. Plastic bag policies

Interventions to reduce the use of plastic bags have been varied in range and scope. Governments all over the world have strategies to

ban the sale of lightweight bags, charge customers for lightweight bags and/or generate taxes from stores who sell them (Fig. 1; Table 1). For example, 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 (Agence France-Press, 2011; Dikgang et al., 2012; Earth Resource Foundation, n.d.). Additionally, many African, Asian and European countries have implemented levies on the use of plastic bags (Zero Waste Scotland, 2014; Poortinga et al., 2013). Levies range in cost, frequency (e.g., Malaysia charges a levy on plastic bags on Saturday only (Asmuni et al., 2015)), and in plastic bag quality (e.g., several countries have levies on bags below a minimum thickness (Dikgang et al., 2012; Block, 2013)). Generally, bans on plastic bag thickness are inconsistent (ranging between <20 to <60 μm), making environmentally informed decisions for consumers and retailers difficult.

Across North America, interventions for plastic bags are limited. Only two cities and six municipalities have imposed levies or bans on plastic bags in Canada. In the U.S., only four states have imposed bans or levies on plastic bags, suggesting that North America's policies for plastic bag interventions are lacking compared to other countries (e.g., Europe). More widespread bans and levies, especially at national levels, should be implemented. Complementary strategies to reduce lightweight plastic bags, include the introduction of reusable shopping bags by some stores. In South America, plastic bag interventions are severely lacking. For example, Colombia plans to reduce the use of plastic bags by 80% by the year 2020, and eliminate their use by the year 2025. In Argentina, only Buenos Aires Province has implemented a plastic bag ban in supermarkets in 2012 and full ban of plastic bags in supermarkets and hypermarkets, commencing 1 January 2017 (Paya, 2016).

According to Jambeck (2015), countries with coastal borders, discharge plastic into the world's oceans with the largest quantities estimated to come from rapidly developing countries (e.g., India and China). However, both India and China have already introduced bans of plastic bags. In 2002, India banned the production of ultra-thin plastic

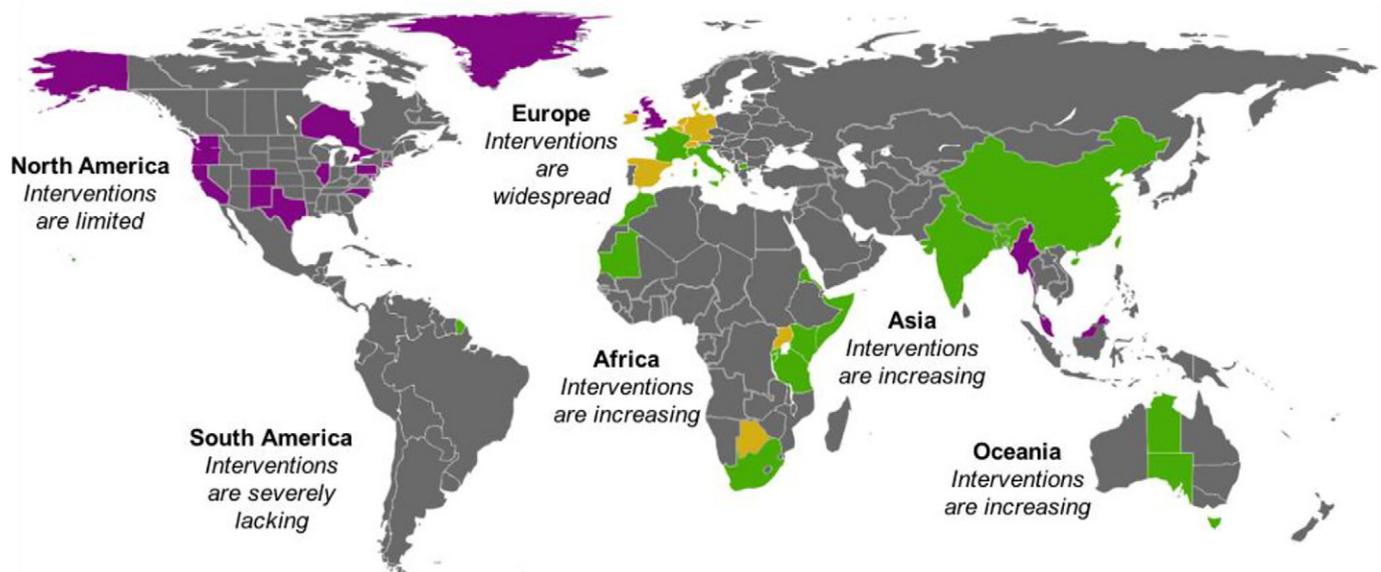


Fig. 1. Phase out of lightweight plastic bags around the world. ■ Plastic bags banned; ■ Taxes on some plastic bags; ■ partial tax or ban (municipal or regional levels) (adapted from Elekhkh - Own work, CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=32400659>).

Table 1
Chronology of global plastic bag policy interventions.

Country (jurisdiction)	Date of ban (Introduction)	Policy framework
Germany	(1991)	Legislation passed to ensure that retail stores providing plastic bags pay a tax or levy. Most retail stores charge 5 or 10 Euro cents/bag. Following the EU announcement, the country will charge 20 cents per bag (Clean Up Australia, 2015; Earth Policy Institute, 2014).
Denmark	(1994)	Legislation was passed that enforces plastic bag manufacturers to pay tax based on the weight of plastic bags. Retail stores are able to pass the cost of the tax on to consumers. Today, plastic bags cost consumers between 37 and 65 US cents (Ritch et al., 2009).
Bangladesh	(2002)	Legislation passed to ban the manufacture and use of plastic bags. One of the major drivers of the ban was the tendency of submerged plastic bags to exacerbate major floods. While the ban has been in place, it has not been strictly enforced. (Earth Resource Foundation, n.d.)
Ireland	(2002)	Legislation passed to create a levy for sale of plastic bags in retail stores. The levy started at 15 Euro cents/bag in 2002, and in 2007, the levy increased to 22 Euro cents/bag. The levy was increased to 44 Euro cents in 2009. Plastic shopping bags designed for re-use are exempt from the levy provided the retailer charges at least 70 Euro cents/bag. The levy increased in 2007 as bags consumed per capita had increased during 2006 (Earth Policy Institute, 2014).
South Africa	2002 (2003)	Legislation passed to place a ban on plastic bags <30 µm thick. Plastic bags >30 µm were subjected to the imposition of a levy. Enforcement of the plastic bag ban has been poor. Acceptance of the levy by consumers has seen high levels of consumption continue (Dikgang et al., 2012)
India	(2002 and 2005)	Legislation passed in 2002 to ban bags <20 µm thick. This was followed in 2005 with a ban of bags <50 µm. In 2016, the state of Karnataka introduced a complete ban on plastic bags. Bans were implemented to prevent bags from clogging municipal drainage systems, particularly in monsoon season. Bans were also implemented to prevent the nation's sacred cows ingesting plastic bags when eating food inside bags, which can cause mortality (Clean Up Australia, 2015).
Taiwan	(2003)	Legislation passed to ban lightweight bags in a number of sectors. The ban was overturned in the food services sector in 2006 due to hygiene concerns (Clean Up Australia, 2015).
Rwanda	2004 (2008)	Rwanda set the goal to become the first plastic-free nation, as part of their overall goal to become a middle-income nation. Legislation was passed to ban the sale, manufacturing, using, and importing of plastic bags (BBC News, 2008; Pilgrim, 2016).
Eritrea	(2005)	Legislation passed to ban the use of plastic bags nationwide (Rayne, 2008).
Tanzania	(2006)	In 2005, an initial ban was made in Zanzibar for bags <100 µm. Legislation was then passed, banning bags <30 µm in the remainder of the country (BBC News, 2008; Earth Policy Institute, 2014).
Botswana	(2007)	Legislation passed to introduce a levy of up to 50 thebe (approximately 5 US cents) per plastic bag (Dikgang et al., 2012).
Canada (Municipal)	(2007–2010)	Six municipalities across Alberta, Manitoba, and Quebec have imposed plastic bag bans. The first of these occurred in Leaf Rapids, Manitoba in 2007 (CTV News, 2007)
Kenya	(2007 and 2011)	In 2007, a ban to plastic bags <30 µm, and a levy was imposed on bags >30 µm (Earth Policy Institute, 2014). Legislation passed to ban plastic bags <60 µm, and continue with a levy for

Table 1 (continued)

Country (jurisdiction)	Date of ban (Introduction)	Policy framework
Uganda	(2007 and 2013)	thicker bags (Agence France-Press, 2011). In 2007, a ban to plastic bags <30 µm, and a levy was imposed on bags >30 µm. In 2013, a ban to the manufacturing and use of most plastic bags. The ban was introduced because of the nation's serious concerns for the environment, as well as the challenges faced by the nation in the management of plastic (BBC News, 2008)
U.S. (California)	(2007–2016)	No state-wide ban exists. San Francisco became the first city to ban plastic bags at checkouts in California in 2007 (Romer, 2010). At least 137 municipal governments (28% by number, not population) have implemented local bans on single-use plastic bags (Ballotpedia, 2016). In November 2016, plastic bags were banned throughout California via a referendum (The New York Times, 2016).
China	(2008)	Legislation passed to ban shops, supermarkets, and sales outlets from providing free plastic bags that are <25 µm thick. For bags >25 µm, a levy was put in place. Exemptions from the ban were in place for hygiene reasons in the handling and storage of fresh food. Adherence by retailers has not been widespread. >80% of retail stores in rural regions have continued to provide plastic bags free of charge. Suiping Huaqiang Plastic, a 20,000-employee plastic bag manufacturer, experienced the ban's economic effects almost immediately. The company went out of business soon after the government announced the plastic bag policy (Block, 2013).
U.S. (Washington D.C.)	2009 (2010)	Legislation passed to help protect the Anacostia River, and money raised from the plastic bag levy is helping to clean up the river (Government of the District of Columbia, 2009; Council of the District of Columbia, 2012).
Myanmar	(2009 and 2011)	The city of Mandalay banned plastic bags. Production, use and sale of bags was banned in the former capital city, Yangon, and the new capital, Naypyidaw (Clean Up Australia, 2015).
Australia	(2009, 2011, 2013)	The states and territories of South Australia (2009), Tasmania (2013), Australia Capital Territory (2011), and Northern Territory (2011) have all introduced bans on plastic bags (Clean Up Australia, 2015).
Hong Kong	(2009 and 2015)	Legislation passed to impose a 50 HK cent levy on plastic bags. In 2009, the levy was imposed at major supermarkets and retail outlets. In 2015, the levy was widened to all retailers. Exemptions from the ban were in place for hygiene reasons in the handling and storage of fresh food (Hong Kong Environmental Protection Department, 2015)
Malaysia	(2011)	The state of Selangor charges a levy on plastic bags on Saturdays. The state of Penang charges a levy every day (Asmuni et al., 2015).
Wales	2011	Legislation passed to place a levy of 5 pence per plastic bag. In the first three years of operation, the levy has raised between £17 million and £22 million (Welsh Government, 2014).
Argentina (Buenos Aires)	2012 (2017)	In Argentina, Buenos Aires Province implemented a plastic bag ban in supermarkets in 2012 and full ban of plastic bags in supermarkets and hypermarkets, commencing 1 January 2017 (Paya, 2016).
Canada (Toronto)	2012–13	The city once had a five cent levy for plastic bags, and an outright ban on plastic bags was sought in 2012. The plastic bag levy ceded, but the banning of plastic bags was rejected the City Council in 2013 (Toronto Environmental Alliance, 2013).
Italy	(2013)	A ban on the sale of non-biodegradable plastic bags. This ban has not been fully implemented due to disputes regarding EU trade laws (Earth Policy Institute, 2014).

Table 1 (continued)

Country (jurisdiction)	Date of ban (Introduction)	Policy framework
Mauritania	(2013)	A ban on manufacturing, using, and importing plastic bags. Anyone using, manufacturing or importing plastic bags could be fined or sentenced to a year in prison. More than 70% of cattle and sheep that die in the capital, Nouakchott, are killed by eating plastic bags (Informal Waste Pickers And Recyclers, 2013).
Scotland	2014	Legislation passed to place a levy of five pence per plastic bag (Zero Waste Scotland, 2014).
England	2015	Legislation passed by British parliament to place a levy of 5 pence per plastic bag. The levy applies at large retail businesses, which are businesses with 250 or more employees. Smaller businesses can also charge the levy on a voluntary basis (United Kingdom Department for Environment Food and Rural Affairs, 2015).
U.S. (Hawaii)	(2015)	Legislation passed to ban non-biodegradable plastic bags. A levy is to be charged for reusable and compostable bags (City and County of Honolulu's Department of Environmental Services, 2015).
EU	2015	Legislation passed that is binding for EU state members. Each nation within the EU is required to take measures to reduce annual average consumption of plastic bags to 90 lightweight bags per citizen by the end of 2019 and 40 per capita by the end of 2025. Alternatively, a nation needs to ensure that by the end of 2018, no more light plastic bags are handed over free of charge to shoppers. The EU considers plastic bags to be lightweight if <50 μm , which includes most plastic carrier bags used in the EU (European Union, 2015).
Canada (National)	(2016)	In February 2016, Walmart Canada began charging customers a 5 cent fee for all shopping bags (Walmart Canada, 2016).
Israel	(2016)	Legislation passed to introduce a levy that is currently set at approximately 3 US cents per plastic bag (Clean Up Australia, 2015).
Netherlands	(2016)	A ban on the distribution of free bags. A levy of 25 Euro cents per bag is advised, but the rate is not enforceable. However, a levy is required. Exemption from the levy applies to bags used for food or preventing food waste (Plastic Soup Foundation, 2016).
Puerto Rico	(2016)	A ban on the use of plastic bags in the Commonwealth commences on 24 December 2016 (Commonwealth of Puerto Rico, 2015).
Morocco	(2016)	A ban on the production, import, sale and distribution of plastic bags commenced on 1 July 2016 (Alami, 2016).
Papua New Guinea	(2016)	A nationwide ban of plastic bags commenced on 1 January 2016. Instead, the government has promoted the use of traditional and locally manufactured bilum bags (Pacific Islands News Association, 2015).
U.S. (New York City)	2016 (2016)	Legislation passed to introduce a levy on plastic bags, which is due to commence on 1 October (Gay, 2016).
Canada (Montreal)	2016 (2018)	In early 2016, the city of Montreal announced a ban on bags <50 μm . This ban is due to commence in April 2018. The imposition of a levy on bags >50 μm is up to the retail outlet. Plastic bag making industry has 23 companies employing >1000 people on the island of Montreal, and a ban is likely to threaten this industry (Retail Council of Canada, 2016).

bags (<20 μm) to prevent clogging of municipal drainage systems and to prevent mortality of cows from ingesting plastic bags containing food. However, enforcement of bans remains a problem (Clean Up Australia, 2015). In China, a total plastic bag ban on plastic bags (<25 μm), and a fee on plastic bags was introduced on June 1, 2008. Plastic bag use fell between 60 and 80% in Chinese supermarkets, and 40

billion fewer bags were used. However, the use of plastic bags remains prevalent particularly among street vendors and smaller stores (Block, 2013).

Although Australia has not ban plastic bags nationally, some states (South Australia, Tasmania and Northern Territory), and some cities have independently banned them. Introduction of the 'Zero Waste' program in South Australia led to a plastic bag ban in October 2008, reducing an estimated 400 million bags per year. No laws have been passed in New Zealand to ban or charge for plastic bags (Clean Up Australia, 2015).

3.2. Microbead policies

Compared to plastic bags, there have been limited interventions to reduce microbeads, but there has been a rapid proliferation in policies to reduce the use of microbeads (since 2014) (Fig. 2; Table 2). Most of these policies relate to the ban of the sale and use of microbeads. The Netherlands was the first country to announce its intent to be free of microbeads in cosmetics by the end of 2016, although no legislation or implementation of a ban has been passed yet (The Economist, 2015). However, the Dutch government and trade organizations have been active in pressuring industry to cease manufacture of microbeads or to remove them from their products. They were also one of the European nations who issued a joint statement requesting a ban of microbeads within the EU (Beat the Microbead, 2016). In Canada, the province of Ontario passed legislation banning the manufacture of microbeads in 2015 (Legislative Assembly of Ontario, 2015). The Canadian federal government classified plastic microbeads as a toxin under the *Canadian Environmental Protection Act* (CEPA), 1999 on June 17th, 2016 (CEPA, 2016). The order was accompanied by a notice of intent to develop microbead regulations, to prohibit the manufacture, import and sale of certain exfoliating personal care products (Walker et al., 2016). In the US, national legislation was passed by the US Congress in December 2015 to control microbead plastics (United States Congress, 2015; Schwartz, 2015).

In 2016, the UK government announced plans to ban microbeads in cosmetics and personal care products by the end of 2017 (United Kingdom Department for Environment Food and Rural Affairs, 2016). The ban followed the successful introduction of the five pence plastic bag charge, which led to six billion fewer bags issued during the first year of implementation (United Kingdom Department for Environment Food and Rural Affairs, 2015). Banning microbeads in the UK is the next step in government action to reduce plastic marine pollution (United Kingdom Department for Environment Food and Rural Affairs, 2016). Encouragingly, policies around microbeads use have been national in scope within Europe and North America. However, no bans have yet been implemented due to the phased approach that many jurisdictions have adopted (usually 2–3 years). There remains uncertainty how these bans will be implemented and enforced, and what impact they will have on the marine environment, as there have been few studies to quantify effectiveness of these policies.

3.3. Effectiveness of policies to reduce single-use plastics

This review highlights research gaps (most notably in follow-up effectiveness monitoring) in current policies that aim to reduce single-use plastic consumption. For example, there are few studies examining effectiveness of microbeads bans, likely because there are currently few policies, and those that do exist, have been inconsistently implemented. For example, bans across North America appear to have been implemented inconsistently (Table 1). States, towns and municipalities throughout the U.S. have legislated bans without agreements of neighbouring regions; particularly where different jurisdictions share watersheds or coastlines.

Although there is little academic literature assessing effectiveness of introduced interventions for single-use plastics, some studies on the

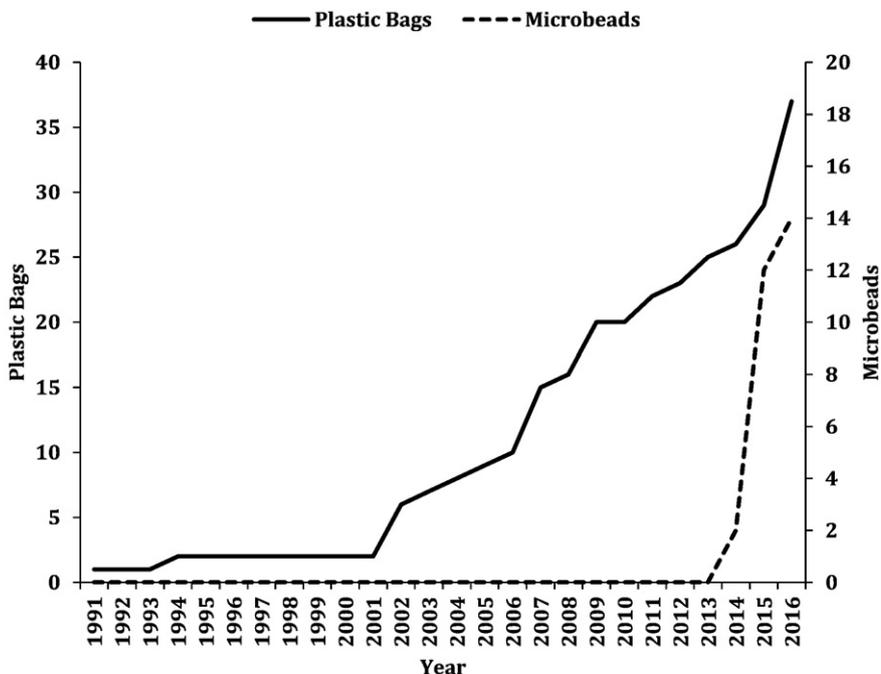


Fig. 2. Timing and number of global plastic bag and microbead interventions.

efficacy of bans or levies of single-use plastic bags have been encouraging (Dikgang et al., 2012; Block, 2013). The 2002 levy (€0.15) in Ireland resulted in an immediate reduction (~90%) in plastic bag use by an order of magnitude, from an estimated 328 bags to 21 bags per capita; and currently at an estimated 14 bags per capita in 2014. The tax was increased to €0.22 in 2007 and increased again to €0.44 in 2009 because of temporary increases in per capita bag use over the same period. Revenues generated from the bag tax were contributed to an Environment Fund (Earth Policy Institute, 2014). Similarly, in Wales, single-use plastic bag consumption declined by 71% between 2011 and 2014 (when a five pence levy was introduced in October 2011). Statistics released in 2012 by the Welsh Government suggested that carrier bag use in Wales had reduced 96% since the introduction of the levy (Welsh Government, 2014). England was the last country in the UK to adopt the five pence charge for plastic bags, although some retailers participated voluntarily prior to the government policy. Following the introduction of the five pence levy in England, plastic bag use at seven major supermarkets dropped by 85% (Smithers, 2016), which translated to approximately six billion fewer bags issued during the first year of implementation (United Kingdom Department for Environment Food and Rural Affairs, 2015).

While limited information is available on plastic bag bans, no studies were found related to efficacy of bans of microbeads. Therefore, research is required to address this gap for a number of reasons. Monitoring can ensure that interventions are being adhered to. In South Africa, insufficient monitoring of plastic bag consumption resulted in an ineffective plastic bag prevention scheme; the levy was too small, and, overtime, reductions in plastic bag use ceased (Dikgang et al., 2012). Research is important, as results that demonstrate widespread improvements to mitigating marine pollution (as a result of interventions), are likely to trigger more bans across different jurisdictions. Research to quantify effectiveness of policies to reduce microbead pollution could include end of pipe testing at wastewater treatment plants before and after policies have been implemented. For example, monitoring of microplastic beads in wastewater effluent could reveal baseline data of microplastic releases into the aquatic or marine environment. Announcements of bans normally occur months or years ahead of implementation of bans, and many jurisdictions use a phased approach for banning microbeads (e.g., 2015 date of ban, then

2017–2019 for commencement). Therefore, monitoring data can be collected prior to, during phasing out and following bans to assess effectiveness of bans.

Following the ban of the sale and manufacture of cosmetics and personal care products containing microbeads, the UK government announced plans to gather evidence of environmental impacts on the marine environment from microbeads in household and industrial cleaning products, as well as microfibers (United Kingdom Department for Environment Food and Rural Affairs, 2016). For example, 25 UK cosmetics and toiletries companies (e.g., Unilever), have voluntarily phased out microbeads from their products and some supermarket chains (e.g., Waitrose) have already stopped stocking products containing microbeads. The UK government has consulted industry and environmental groups to establish how a ban could be introduced. Manufacturers across the UK are exploring natural alternatives, including nut shells, salt and sugar, which have exfoliating properties but do not pose threats to the environment (United Kingdom Department for Environment Food and Rural Affairs, 2016). Although the Dutch government lack legislation to ban microbeads in cosmetics, working with industry and trade organizations has resulted in ~80% of cosmetic companies being microbead-free by 2017 (The Economist, 2015; Beat the Microbead, 2016). In the USA, many cosmetic companies have also been voluntarily phasing out microbeads (e.g., Crest) (American Dental Association, 2014).

While some studies highlight a reduction in single-use plastic bags following the introduction of policies around plastic bag use (Block, 2013; Welsh Government, 2014; Clean Up Australia, 2015; Smithers, 2016), research related to environmental outcomes is still lacking. Despite limited outcome data, it is recommended that the rapidly growing global trend of increased levies or, better still, outright bans continue. It is also recommended that all microbead bans become implemented, and that further bans continue to be introduced. Research is required to assess whether reductions in single-use plastic bags are maintained, and indeed, more research is required to determine whether these reductions are having a positive impact on aquatic or marine environments. Similar research will be required following implementation of microbead bans. Lag times for commencement of microbead bans (normally 2–3 years following announcements), create issues for immediate source control. However, this lag time could provide lead time to

Table 2
Chronology of global microbead policy interventions.

Country (jurisdiction)	Date of ban (commencement)	Policy framework
U.S. (Illinois)	2014 (2017–2019)	In June 2014, the state legislature passed legislation that was due to phase in a ban of the sale and import of synthetic microbeads between 2017 and 2019 (Illinois General Assembly, 2014).
Austria, Belgium, Sweden, Netherlands, Luxembourg (Multi-national)	2015	Through the Council of the European Union (EU), these countries issued a joint statement requesting a ban of microbeads within the EU (Council of the European Union, 2014).
Canada (Ontario)	2015 (2017)	The Ontario parliament passed legislation to ban microbeads in 2015. The legislation prevents the manufacture of microbeads in Ontario. This ban is to commence in June 2017 (Legislative Assembly of Ontario, 2015).
U.S. (National)	2015 (2017–2019)	In December 2015, the <i>Microbead-Free Waters Act</i> of 2015 was passed in the U.S. Congress, which was an amendment to the Federal Food, Drug, and Cosmetic Act to ban rinse-off cosmetics that contain intentionally-added plastic microbeads beginning on January 1, 2018, and to ban manufacturing of these cosmetics beginning on July 1, 2017. These bans are delayed by one year for cosmetics that are over-the-counter drugs. The ban is to be phased in between 2017 and 2019. The ban will cover the manufacturing and importing of cosmetic products and over-the-counter medication that include synthetic microbeads (United States Congress, 2015).
U.S. (Colorado, Maine, New Jersey)	2015 (2017–2019)	In March 2015, the state legislature passed legislation that was due to phase in a ban of synthetic microbeads between 2017 and 2019 (Colorado Legislative Services, 2014; Maine State Legislature, 2015; Levine, 2016).
U.S. (Wisconsin)	2015 (2017–2019)	In July 2015, the state legislature passed legislation that was due to phase in a ban of synthetic microbeads between 2017 and 2019 (Wisconsin State Legislature, 2016).
U.S. (Indiana)	2015 (2017–2019)	In April 2015, the state legislature passed legislation that was due to phase in a ban of synthetic microbeads between 2017 and 2019 (Bauer, 2015).
U.S. (Maryland)	2015 (2017–2019)	In October 2015, the state legislature passed legislation that was due to phase in a ban of synthetic microbeads between 2017 and 2019 (General Assembly of Maryland, 2015).

Table 2 (continued)

Country (jurisdiction)	Date of ban (commencement)	Policy framework
U.S. (Connecticut)	2015 (2017–2019)	In June 2015, the state legislature passed legislation that was due to phase in a ban of the sale and import of synthetic microbeads between 2017 and 2019 (Connecticut General Assembly, 2015).
U.S. (California)	2015 (2017–2019)	In October 2015, the state legislature passed legislation that was due to phase in a ban of the sale and import of synthetic and biodegradable microbeads between 2017 and 2019 (California Legislative Information, 2015).
U.S. (New York) – Albany, Erie, Chautauqua, Cattaraugus and Suffolk counties	2015 (2017–2019)	Erie County was the first of the five counties to ban microbeads. This county's ban includes the banning of biodegradable microbeads. While Erie County planned to ban microbeads in 2016, it is not being strictly enforced due to the many products in retail stores that contain microbeads (Erie County Legislature, n.d.; Tan, 2016).
U.K. (Multi-national)	2016 (2018)	The U.K. has pledged to ban microbeads by the end of 2017 (BBC News, 2016; United Kingdom Department for Environment Food and Rural Affairs, 2016).
Canada (National)	2016 (2018–2019)	Canada became the first country to list microbeads as a "toxic substance" (Government of Canada, 2016a). Proposed regulations are to ban the manufacture, import, and sale of products containing microbeads to be phased in during 2018 and 2019 (Environment and Climate Change Canada, 2016; Government of Canada, 2016b).

develop appropriate and effective monitoring (i.e., before and after measurements). Accurately quantifying effectiveness of various strategies (i.e., source controls), would require internationally coordinated monitoring campaigns where data could be synthesized across studies, to provide a global picture of the effectiveness of intervention strategies (GESAMP, 2016). This research should seek to measure and demonstrate benefits of these policies using quantitative methods, benefits to the environment, economy and society should also be considered.

Education and outreach programs to modify behaviour should be widely adopted (Kershaw et al., 2011). Incorporating ocean education, pollution, and waste management in schools could be extremely valuable. For example, a study by Hartley et al. (2015) found that school children in the UK significantly improved their understanding of the causes and negative impacts of marine litter after education intervention related to plastic marine debris. Education and behavioural change of children is crucial as they represent an important source of social influence among their peers, parents and community (Hartley et al., 2015). Targeting youth and other stakeholders (e.g., citizens, governments, industry and NGOs) is an effective way to promote positive change and help increase awareness, through events like World Oceans Day (<http://www.worldoceansday.org/>) (Pettipas et al., 2016).

Policy tools discussed in this study (e.g., bans, levies) are just some of the solutions required to tackle this growing global plastic debris problem. It has been reported that one of the best strategies to mitigate

plastic pollution would be to reduce its consumption at source (Jambeck, 2015). Therefore, it is recommended that education, outreach and awareness about the issues of marine plastic pollution, particularly the contribution of plastic bags and microbeads, be conducted. As awareness grows, presumably plastic bag and microbead marine pollution would also decline.

4. Conclusions

This review of current international market-based strategies and policies to minimize single-use plastics (plastic bags and microbeads) provides important information and highlights gaps for decision and policy makers. While measures to reduce plastic bag pollution have long been established, many countries still lack any implementation strategies. Likewise measures taken to mitigate microbead pollution are relatively new and are restricted to just a few countries. Lag times for commencement of microbead bans delays immediate source control, but could provide opportunities to develop appropriate and effective monitoring campaigns.

Internationally, all interventions to reduce single-use plastics vary in range and scope. Policies have been developed across a number of nations to ban primarily the use and sale of, but also the manufacturing of microbeads. Measures to reduce plastic bag pollution have included bans (including both full and partial) and levies, and these interventions have occurred both regionally and nationally. Although reduction strategies provide tools to reduce single-use plastics at source, it is recommended that consistent measures continue to be implemented to mitigate plastic bag and microbeads pollution. However, it is equally important that research measure the positive impacts of these measures in the short- and long-term. Education campaigns will likely help to further reduce plastic pollution caused by microbeads and plastic bags at source.

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