An Assessment Report on Microplastics

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What are Microplastics?

The category of 'plastics' is an umbrella term used to describe synthetic polymers made from either fossil fuels (petroleum) or biomass (cellulose) that come in a variety of compositions and with varying characteristics. These polymers are then mixed with different chemical compounds known as additives to achieve desired properties for the plastic's intended use (OceanCare, 2015). Plastics as litter in the oceans was first reported in the early 1970s and thus has been accumulating for at least four decades, although when first reported the subject drew little attention and scientific studies focused on entanglements, 'ghost fishing', and ingestion (Andrady, 2011). Today, about 60-90% of all marine litter is plastic-based (McCarthy, 2017), with the total amount of plastic waste in the oceans expected to increase as plastic consumption also increases and there remains a lack of adequate reduce, reuse, recycle, and waste management tactics across the globe (GreenFacts, 2013).

The term 'microplastics' has only surfaced relatively recently and has since had different definitions according to different researchers. In 2003, Gregory and Andrady defined microplastics as particles 0.06-0.5mm in diameter with larger particles still barely visible called 'mesoplastics' and visible particles known as 'macroplastics'. Others since then, including the National Oceanic and Atmospheric Administration (NOAA), have defined microplastics as particles <5mm in size (Andrady, 2011); going forward, this definition of <5mm will be used for this document with anything larger classified as macroplastics.

These tiny particles easily pass through water filtration systems and end up both in discharged water and composted sludge from wastewater treatment plants (NOAA, 2016). Microplastics have become the most abundant form of solid-waste pollution and have been found in all oceans including the deep-sea where their concentration is four times higher than that found in coastal waters (Volz, 2015). The average consumer discards about 2.4mg of microplastics per day with around 1 million tonnes being released into wastewater annually (Earth Day Network, 2018). While interactions between macroplastics and the marine environment are relatively well-known, the effects of microplastics including non-lethal impacts, chemical additives, and regarding smaller organisms are less researched (GreenFacts, 2013).

Figure 1. *Images showing the size and variability of microplastics. (Left image taken from [Florida Sea Grant]; Right image taken from [Clean Future])*

Where Do Microplastics Come From?

Microplastic particles can arise from a variety of different sources but within the definition there are generally two categories:

Primary Sources

Primary microplastics are those which have been intentionally created to serve a production purpose and either voluntarily added to products, an inherent byproduct of some process, or through unintentional release (GESAMP, 2015). Examples include microbeads used in personal care and cleaning products, fibres created for synthetic textiles, and intermediate plastic feedstock in the form of pellets, nurdles, mermaid's tears, etc.

Microbeads are the one type of microplastics that the general public is most familiar with; tiny pieces of manufactured polyethylene plastic are added to a variety of products to be used for abrasion purposes. Plastic microbeads first appeared in personal care products (PCP) about fifty years ago and since then have been increasingly replacing natural ingredients with little knowledge on the part of the consumers (NOAA, 2016). The addition is thought to improve the abrasion effectiveness of some PCP such as peels, scrubs, toothpastes, etc. (OceanCare, 2015) but can also be used to change a product's viscosity or delivery of active ingredients. In some PCP, the microbeads can represent 10% of the product's weight (Boucher & Friot, 2017) or 90% of the ingredients (Cameron, 2018). In the past, studies have estimated that the United States was responsible for around 200 tonnes of microbeads from PCP and about half would pass through sewage treatment facilities before entering the ocean (GESAMP, 2015a). Other products that use microbeads but are lesser known to the public include printer toner, oil and gas exploration, textile printing, dentist tooth polish and other medical applications, cleaning products, and sandblasting at shipyards (Weeks, 2018). Unfortunately, these types of microplastics only last as long as the product is used and are often directly introduced into wastewater streams via household, hotel, hospital, and industry drains.

Microplastics can also be formed as an inherent byproduct of either a product or process and this mechanism offers the largest variety of sources (Pravettoni, 2018). The industrial production or maintenance of macroplastics often results in microplastic dust that then enters waterways or becomes airborne; such uses include cutting, polishing, and molding plastic items in places such as shipyards, boat repair shops, car repair shops, ski waxing shops, etc. Maintenance of maritime structures offer the highest number of point sources for microplastic dust due to the frequent use of plastic based paint. Already painted structures such as ships, shipyards, offshore rigs, bridges, pipelines, etc. can cause a release of microplastic dust when they are pressure washed or sandblasted for cleaning, whereas the painting process itself can lead to unintentional release of microplastics into the ocean or waterways (Mepex, 2014). Marine coatings include solid coatings, anticorrosive paint or antifouling paint and several different types of plastics are found in these including polyurethane, epoxy coatings, vinyl, and lacquers (Boucher & Friot, 2017). Studies have come out showing that up to 10% of oceanic microplastic pollution originates from microplastic paint dust which has also been observed to coat the ocean surface (Earth Day Network, 2018).

Not only does industrial production and maintenance produce microplastics, so to does normal wear and tear from consumer use. Within a home there can be many sources of microplastics from everyday use of common household items both indoors and outdoors including, as stated previously, the removal of paint from heavy washing and scrubbing along with the weathering of plastic items such as toys, floor coverings, and furniture (Mepex, 2014). The most recent source of microplastic pollution has been identified as microfibres that come from synthetic textiles which has been estimated to account for up to 85% of the total human material found along shorelines (Earth Day Network, 2018). The most well known of this source is synthetic plastic fibres found in clothing, the biggest culprits being nylon, polyester, and spandex, and typically made of polyester, polyethylene, acrylic or elastane (Boucher & Friot, 2017). These fibres are often ripped loose from the garment under normal wear and tear but are especially vulnerable in the washer and dryer; studies have shown these types of clothes can lose up to 700,000 microfibres with every wash and one study concluded that a single fleece jacket can lose 1.7 grams of microfibres with every wash (Cameron, 2018). Wet wipes are also considered to be a synthetic textile as both plastic and natural fibres are woven together; even those marketed as flushable often remain in the sewer systems for long stretches of time and act as an ongoing source of plastic fibres (Bailey, 2018).

Many smaller sources of microplastics from consumer use exist such as city dust, commercial, agriculture, and maritime use. The term 'city dust' is very broad and encompasses a variety of sources that individually contribute very little to the amount of microplastics but collectively account for a good majority of microplastics that come from urban environments. The biggest culprit of microplastics are car tires as they erode during use, although tires are made from natural rubber about 60% of each one is comprised of synthetic polymers such as Styrene Butadiene Rubber. Tire dust can then be mixed with other road dust, stemming from road markings and sealants, and enter waterways via wind and urban runoff (Boucher & Friot, 2017). One car tire can shed up to 20 grams of plastic dust every 100 kilometers (Earth Day Network, 2018). Separate from city dust are commercial/public uses of plastics that also lead to microplastics being emitted; included in this is office dust and any other buildings that use wall-to-wall carpeting, plastic pipeline systems, and printer toner (Mepex, 2014). Many companies also use plastics in their services, such as effluent from cleaning companies and laundromats, or in their products which are then used in public spaces, such as tennis balls, cigarette filters, glitter, tea bags, and takeaway cups; many of these products also contain a paper component which breaks down but leaves the plastic remaining to enter the environment (George & McKay, 2017). In more specialized industries, maritime microplastic byproducts stem from effluent and plastic rope while agricultural microplastic byproducts most commonly stem from different types of filters such as mulch.

A final inherent byproduct source stems from the good intentions of waste handling and recycling of plastic waste. Plastic waste is commonly shredded or fragmented in order to be recycled or easily contained but the improper handling of the resulting fluff and fractions can lose microplastic into runoff, especially if the process takes place on a ship. Ships that are set to be decommissioned or installed offshore often go through shipbreaking processes which can also introduce microplastics directly into the harbor or ocean (Mepex, 2014).

Primary microplastics can often be introduced into the oceans and waterways through unintentional release either by transport or fires. During pre-production of any plastic product, the primary form of plastic polymers come in either a powder or pellet form; pellets are also known as nurdles, mermaid's tears, and nibs (Boucher & Friot, 2017). These are then transported to producers who have plastic transformers that can convert the powder or pellets into plastic products, usually by melting and moulding into a desired shape (Beaulieu, 2018). Due to poor handling or accidental spillages, which can occur along the entire plastic lifecycle, these pellets and powders can be unintentionally leaked into the marine environment and this is especially true near industrialized areas or ports (OceanCare, 2015). Fires, either planned or uncontrolled, that involve any type of plastic or plastic waste will introduce plastic dust emissions into the atmosphere where it will either stay or enter the hydrological cycle (Mepex, 2014).

Secondary Sources

Secondary microplastics arise with the fragmentation of larger pieces of plastic or 'parent' plastics; multiple processes exist that help deteriorate these macroplastics including natural defragmentation in the sea, biological contributions, and remobilization (Green Facts, 2013). Some studies have estimated that up to 75% of the microplastics in the ocean originated from macroplastics and while these macroplastics can be broken down through various processes, plastic never truly disappears and only gets smaller and smaller (Rennie, 2017).

The illegal, unwanted, and unregulated handling of waste both on land and at sea can introduce a variety of macroplastics into the ocean. Terrestrial sources, such as legal and illegal landfills, public littering, and construction waste, are a less direct route of macroplastics into waterways and the ocean whereas maritime sources, such as seaside leisure, aquaculture facilities, and offshore shipping, are more direct due to the activities occurring on or near the water. Once on the beach or in the sea, macroplastics are subject to fragmentation caused by natural environmental factors, such as physical abrasion by waves or on rocks and UV radiation, which weakens the macroplastic and forms millions of microplastics over time (Beaulieu, 2018). Fragmentation is most effective on beaches due to the high levels of UV radiation and the physical abrasion by waves, especially on beaches with high wave activity, but once the plastic gets swept offshore and submerged the fragmentation will slow as the UV radiation will be reduced and the temperatures will cool (GESAMP, 2015).

Although the natural fragmenting process is the most common way macroplastics become microplastics, other factors can contribute such as biological ones and remobilization. Certain types of marine fauna, such as isopods, regularly bore into plastic contaminated ocean floor sediment which can cause fragmentation while other types of marine fauna with gizzards, such as mollusks and some fish, can shred plastic into microplastics to be released upon decomposition or passed up the food chain. Sea birds will also regularly help the fragmentation process by taking plastics from the sea onto land to be used in their nests, this allows the plastics to be more exposed and break down faster. Many remobilization actions can also stir up plastic contaminated sediment and encourage more fragmentation to occur; ship propellers, dredging of the sediment floor, and the excavation of soil in construction sites are all forms of remobilization and can increase fragmentation (Mepex, 2014).

As the plastic and microplastic pollution has grown both as a problem and an environmental topic, a variety of companies have begun producing 'biodegradable' plastics as an alternative to reduce the amount of plastic waste in the environment. These can be classified as 'oxo-degradable', 'hydro-degradable', and 'photo-degradable' depending on what processes are suited to break down the plastic, oxidation, hydrolysis, and UV radiation respectively (OPA, 2018). Although the name 'biodegradable' suggests a composition of bio-material (i.e. plants), most of the time these are created using oil in the same manner as conventional plastics and certain additives are added during production to change the behavior during the break down process (FuturEnergia, 2007). While these additives help speed up the process of macroplastics breaking down and large plastic items appear to disappear more rapidly than conventional plastic, the resulting microplastics created are no different than what is already found in the ocean (Kubowicz & Booth, 2017). Ideally, these 'biodegradable' plastics will be broken down by microorganisms into water, carbon dioxide, and bio-material but rarely is that the case; most of the products labeled as 'biodegradable' have passed several American Society for Testing and Materials (ASTM) standards of biodegradability but these tests have unique conditions designed to mimic specific environments such as a bioreactor landfill or an anaerobic digester. These unique environments are much hotter and have more oxygen, light, etc. when compared to a marine environment and so far petroleum-based plastics with biodegradability additives have been unable to meet the one standard designed for biodegradability in marine environments (Cramer, 2016).

What are the Consequences of Microplastics?

Marine Ecosystem Health

With the plastic life cycle most often ending in the ocean, many problems arise due to the persistent nature of plastic in the marine environment including simply the ingestion of microplastics along with the chemical additives and other pollutants the plastics can transport. Although macroplastics, specifically plastic bags, can often be mistaken as food for some marine species, microplastics can also be consumed by marine organisms both in the deep-sea and on top of the water (Rhode, 2016); many microplastics will remain on the water's surface due to their buoyancy and only travel to the deep-sea through consumption and excretion by marine organisms (Katija et al., 2017). Studies have shown that the concentration of microplastics is actually four times greater in the deep-sea compared to more shallow, coastal waters and upwards of 73% of deep-sea fish have ingested microplastics during their lifetime, though this is most likely due to their migration to the surface at night to feed on microorganisms (Chow, 2018). Almost 100 fish species have been recorded to ingest microplastics either through accidental uptake during filter-feeding or through intentional uptake by mistaking the plastic for food or by eating organisms that have already eaten microplastics. A big component in the intentional ingestion relies on the size and composition of microplastics as the small size resembles that of zooplankton typical in a variety of diets. Although there is a knowledge gap regarding the long term harmful effects of the ingestion of microplastics by fish, some studies have suggested and seen in smaller organisms that the ingestion can impact buoyancy control, cause internal ulcerations, block the digestive tract, and impair the satiation signals causing the organism to starve (BLASTIC, 2018).

Microplastics are also dangerous due to their unique ability to transport both the chemical additives originally included during production as well as pollutants the microplastics may encounter in the environment after disposal. Due to the synthetic material plastics are made from, most microplastics are hydrophobic in nature and have a large surface area to volume ratio; these two characteristics are quite favorable in that both algae and persistent organic pollutants (POPs) can easily absorb onto the microplastics and be transported accordingly (Viršek et al., 2016). Microplastics can become colonised by algae within days of being in the marine environment, this algae then produces DMS as it naturally breaks down which is a sulphur smell used by almost all marine organisms as an indication of food including fish, sea turtles, whales, and seabirds (Parker, 2016). As a result, many species will often mistake microplastics for food due to the sight and smell mimicking that of algae (Harvey, 2017). At a smaller scale, zooplankton often confuse microplastics for food simply for their size being comparable to other food sources (Valentine, 2015). POPs are toxic chemicals such as industrial chemicals, pesticides, and unwanted wastes that have the ability to bioaccumulate in both animals and humans; by themselves POPs can already travel vast distances through waterways and while airborne but attaching to microplastics allows easy entry into food webs (IPEN, 2018). The toxic levels from bioaccumulation can impact not only the organism that initially ingests the microplastic but the path up the food chain it takes.

Water Quality

As microplastics have such a long residence time within the marine environment they have the ability to alter the quality of the water body due to their ability to transport pollutants and through the creation of plastic biofilms. Water quality standards in the United States (US) are approved by the Environmental Protection Agency (EPA); these standards detail the condition that a water body shall be kept in to suit its designated uses and is the legal basis for controlling pollutants entering waterways (EPA, 2018). Some of the main indicators used when testing water quality include the amount of chlorophyll-a present, the amount of nutrients such as phosphorus and nitrogen present, the amount of dissolved oxygen present, the pH, and the water clarity; all of these can be negatively impacted by the presence of microplastics and in turn can degrade the water quality. As a vessel, microplastics can transport fertilizers from upstream systems into larger bodies of water which can increase the amount of nutrients leading to an increase in the algal growth, an increase in chlorophyll-a, and a decrease in the amount of dissolved oxygen when the algae dies. Fertilizers and POPs can also interfere with the pH of the water body and these changes in water quality standards can make the water body unfit for recreation, drinking water, fishing, etc. A disruption in the pH can cause unsuitable conditions for the species that live there, upsetting both the food chain and the ecosystem as a whole (State Gov of Victoria, 2017).

Human Health

Although most microplastics end up in the marine environment, their negative impacts certainly also extend to human health, usually through the consumption of fish, but in recent years studies have found microplastics also extremely prevalent in other foods, drinking water and the air. Recently, as the issue of microplastics becomes more mainstream, a variety of studies have come out indicating the presence of microplastics in sea salt (Kelly, 2017), honey (Liebezeit & Liebezeit, 2015), and German beer (Liebezeit & Liebezeit, 2014) in addition to the already known presence of microplastics in fish. Due to the early stages of research, the studies claiming microplastics in these various foods have been met with some controversy as there is currently no standardized ways of testing for microplastics in food. In the past year, a study has just been launched to look directly into the human health effects that may be caused by the presence of microplastics in fish (Chow, 2018a); in all cases, large gaps of knowledge currently exist for this type of research and this must be taken into account when discussing microplastics in relation to humans.

In 2017, a study published found that tap water in America was contaminated with microplastics 94% of the time (Morrison & Tyree, 2017). A study published in 2018 found that 93% of bottled water brands across the globe are contaminated in some way by microplastics and an average of 10 microplastic particles (>100um) and 325 microplastic particles (6.5-100um) can be found in every litre of bottled water (Mason, Welch, & Neratko, 2018). After these studies were published, the World Health Organization (WHO) launched a health review to assess the potential harms of microplastics in drinking water; although there is no current evidence to suggest microplastics negatively impact human health, the health review will be looking into whether a lifetime of ingestion can have an impact (Shukman, 2018).

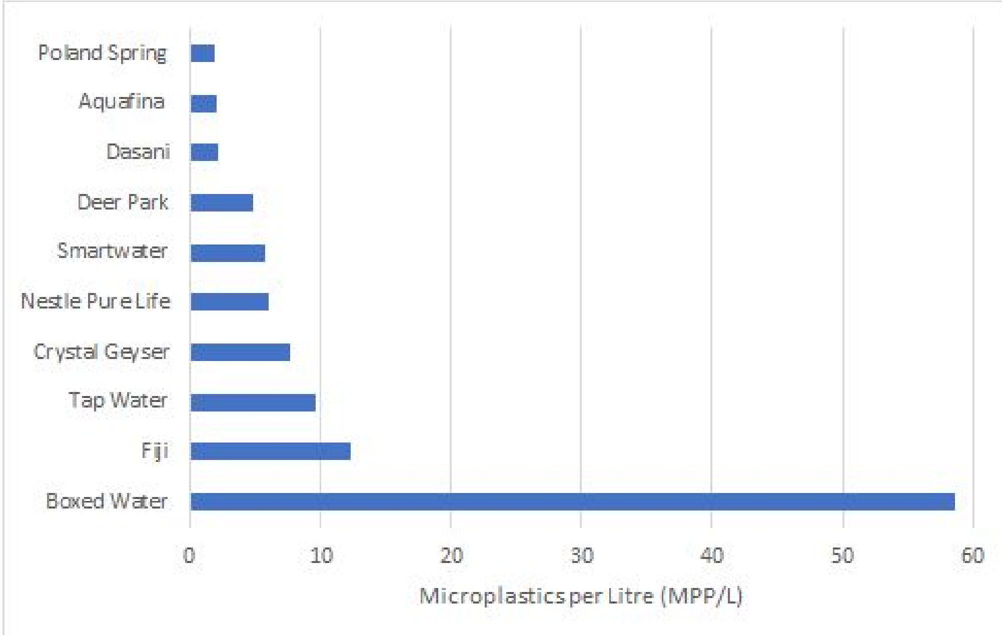


Figure 2. *Graphical representation of the findings from the two studies cited in the above paragraph concerning microplastic particles in both American tap (Morrison & Tyree, 2017) and bottled water (Mason, Welch, & Neratko, 2018).*

Already, microplastics have been detected in atmospheric dust, synthetic fibres have come up in human lung biopsies (Prata, 2018), and microplastics have been shown to travel across a mother's placenta. Despite all this, leading experts admit there are knowledge gaps and the true risk of microplastics to human health is unknown (Boyle & Sheets, 2018). Studies to reduce these knowledge gaps are mainly driven by what scientists fear could result from breathing in microplastics; any chemicals attached to them could end up in the lower parts of our lungs or spread to our circulatory system, some of the chemicals used on microplastics have been shown to interfere with hormones, most microplastics tend to attract other chemicals like a magnet, and even their small size could cause breathing problems. These methods of transportation also mimic that of vehicle emissions and traditional fossil fuel air pollution which further leads scientists to believe there are harmful effects to airborne microplastics and prompting calls to label plastics as toxic once they enter the environment (Johnston, 2016).

What Policies/Practices are in Place to Regulate Microplastics?

Regional Level

Outer Banks, North Carolina

Although North Carolina hasn't seen any regional regulations to combat microplastics directly, any type of legislation that aims to reduce plastic consumption helps in the long run by stopping secondary microplastics at their 'parent' products such as disposable plastic bags found in grocery stores and other retailers. Back in 2009, then-Senator Marc Basnight (D-Dare) wanted to see less plastic bags on the beaches of the Outer Banks and championed the passing of the Outer Banks Plastic Bag Ban which made the area the second in the nation to implement such a ban at the regional level. The bill encompassed Hyde, Dare, and Currituck Counties and was designed to reduce litter on the beaches while also helping protect both the local marine fauna and the aesthetic beauty of the shoreline; its passing confirmed the then-Democratic majority General Assembly's commitment to both the environment and the qualities that brought visitors to the Outer Banks and sustained local residents (Bonner & Doran, 2017). The ban detailed that retailers had to replace disposable plastic bags with paper bags and offer some form of an incentive for every reusable bag used by a customer; there were some exceptions made such as durable plastic bags that had handles, were designed for reuse, and were at least 2.25mm thick were allowed, as well as stores that were less than 5,000 sqft and had less than 5 stores in the state did not have to follow the ban (Crist, 2017). With the passing of the ban in 2009, all large chain retailers had to comply and by 2010 the ban extended to all retailers in the Outer Banks; the ban was temporarily lifted during the 2011 year due to a hurricane (Shirley, 2017).

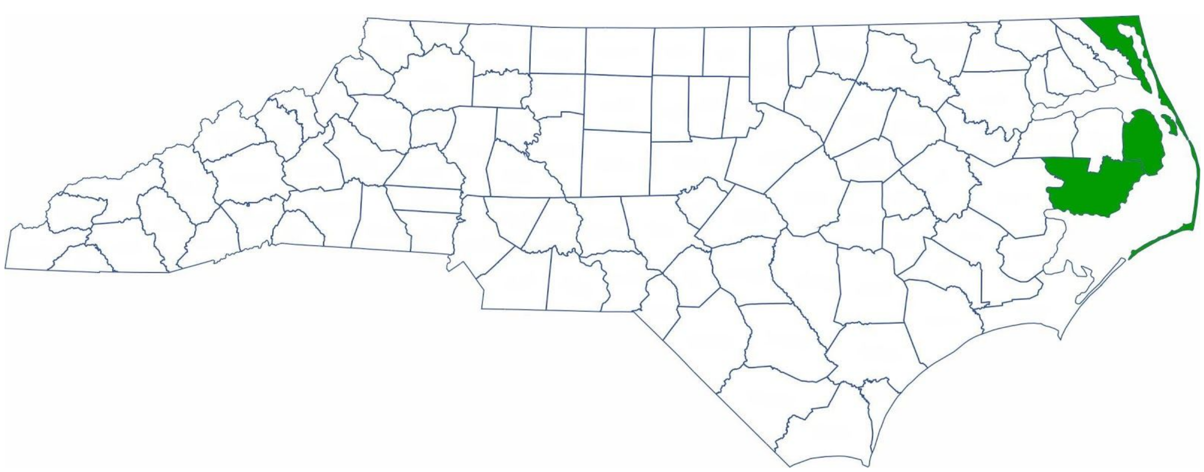


Figure 3. *Map of North Carolina counties where the Outer Banks Ban was in effect from 2008-2017, shown in green.*

In 2017, local EPA scientists discovered engineered chemical compounds, most notably GenX, in the Cape Fear River just downstream of a chemical plant known as DuPont that was in operation from 1970 to 2015. GenX is potentially harmful to human health and most drinking water facilities cannot filter it out, the chemical being found in residential wells above state standards levels created a huge public outcry leading to multiple lawsuits, political debates, and a call for more research so further action could be taken (Clabby, 2017). In February 2017, House Bill 56 (HB 56) was introduced in North Carolina's General Assembly with the aim to require hazardous dam owners to develop Emergency Action Plans but as time went on the bill amassed 20 other provisions before it was passed in late 2017. One of those provisions became the main selling point, allocating $435,000 to the Cape Fear Public Utility Authority and the University of North Carolina at Wilmington to research the GenX chemical in an effort to develop a solution; the other provisions contained various environmental law additions and repeals including one provision to repeal the Outer Banks Plastic Bag Ban (Sechley & Nowlin, 2017). HB 56 was quickly passed through legislation once the GenX amendment was attached and although the governor vetoed it, the General Assembly voted to overrule and the law was passed. In its final form HB 56 was part of a conference report that passed through both chambers and therefore no amendments could be made to it; although Governor Roy Cooper (Dem) vetoed it, the Republican controlled General Assembly capitalized on the GenX issue to pass the bill (Wagner, 2017). Retailers were free then immediately to reintroduce disposable plastic bags in their stores and nothing could be done at the local level as local bans are not allowed without a General Assembly approved referendum due to the Dillon Rule (Crist, 2017).

During the nine years the ban was in effect, there were no strong attempts to get the ban repealed but once the provision was introduced a variety of conservative-leaning statewide groups and Republican Senators were quick to voice their approval. The provision itself was lead by the efforts of Representative Beverly Boswell (R-Dare) and Senator Bill Cook (R-Beaufort) and a variety of other Republican politicians who say they had been waiting to repeal the ban since 2009, citing a variety of reasons why the ban does more harm than good and negatively impacts the local economy (Jarvis, 2017). The other big proponent for the repeal was the North Carolina Retail Merchants Association that cited increased costs from the ban did more harm than good. On the flip side, the introduction of the provision drew a lot of public backlash with many residents, lawmakers, businesses, county commissioners, and municipal governments of the Outer Banks stating their opposition to the repeal. The Outer Banks Chamber of Commerce was quick to voice its own opposition to the repeal with the Dare County Board of Commissioners and other town boards sending letters or passing resolutions that also opposed the repeal. The opposition front mostly targeted those in the General Assembly rather than the large chain retailers with many smaller, local businesses stating they had already adapted to the ban (Walker, 2017).

Those that supported the repeal of the ban cited that the ban was unconstitutional, negatively impacted the economy, and was ineffective as reasons to repeal the ban. Representative Chuck McGrady (R-Hendersonville) has said that the plastic bag ban itself was unconstitutional as it only affected a few beach towns instead of being a statewide ban (Bonner & Doran, 2017). The GOP used the repeal to give major businesses a break, citing the ban cost businesses in fines and penalties if they were noncompliant along with figures showing that the switch from plastic to paper cost a business an average of $40,000 as paper bags themselves cost eight times as much to purchase (Marchello, 2017). Many conservatives have also said that the repeal was necessary in order to encourage merchants to create more jobs and strengthen the economy, as the businesses most affected were local ones instead of the large chains. It has also been postulated that most businesses in the Outer Banks already were not in compliance with the ban and that since its introduction there have been more plastic bags found on the shores and there has been no correlation between the ban and the number of bags found between 2008 and 2011 (Kozak, 2017). Increased consumer education and recycling efforts have been claimed to be the better solution to not only reduce the presence of disposable bags in the environment but all litter and many have pointed out that consumers always have the option to choose the reusable option even if the ban has been repealed (Crist, 2017).

Those that opposed the repeal of the ban cited the environmental implications, the support for the ban, and the lost cause of recycling. Disposable plastic bags have been said to be the second most deadly type of litter to marine fauna, only behind fishing lines, due to their similar appearance to jellyfish and their slow decomposition rates (Kozak, 2017). A 2014 survey even found that there was a reduction of plastic bags found on shore since the introduction of the ban. Many of the local residents, businesses, etc. have also appreciated the effort to reduce the amount of litter found on beaches as litter is bad for business; a reduction of litter typically increases tourism to the area and no evidence has been found to show that the ban negatively impacted tourism . A 2011 survey of Outer Banks residents found there was a positive response to the ban and many local businesses have come forward since the repeal to distance themselves from the repeal decision (Longest & Sechley, 2017). Evidence has also come out to directly contradict the supporters of the repeal who claim that increased voluntary recycling efforts would be more effective than the ban itself. Only 12% of disposable plastic grocery bags and 1% of plastic bags in general are ever returned for recycling; many recycling facilities will no longer accept plastic bags as they must be separately collected due to their tendency to clog recycling machines (Kozak, 2017). There is also a huge loss in profit associated with plastic bag recycling, for one ton of plastic bags that sell for $32 it takes $4,000 to recycle for a loss of $3,968 (Longest & Sechley, 2017).

Other United States Regions

While the Outer Banks Plastic Bag Ban was second in the nation and comprised three separate counties, the first plastic bag ban in the nation only encompassed the city of San Francisco, California. Back in 2007, the city of San Francisco passed a law banning the use of single-use plastic bags in large grocery stores; numerous Bay Area cities followed suit in later years with similar or more strict bans and in 2012 San Francisco widened the ban to include all stores and restaurants within city limits (Save The Bay, 2018). Following the Outer Banks Plastic Bag Ban, in 2010 Washington D.C. saw its own version of a plastic and paper bag fee to combat the finding that plastic bags were the number one source of litter found in the nearby Anacostia River; the law implements a 5 cent fee for every carryout plastic or paper bag given out by any business that sells food or alcohol with some exceptions (D.C. DOEE, 2018). Since its implementation, bag use dropped by 60 percent and bag pollution in the Potomac River dropped by 72 percent in the first four years (Longest & Sechley, 2017). Later on in 2010, Los Angeles County passed its own plastic bag ban that prohibits the distribution of single-use plastic bags in a variety of businesses and charges a 10 cent fee for every paper bag provided (Clean LA, 2018). During its first year, plastic bag use decreased by 95 percent and since then 13+ cities in the county have passed their own bans. In the 11 years since San Francisco passed its first ban, 150+ cities across the nation have passed some form of a plastic bag ban with numerous others pending in the legislature (NCSL, 2018). As of July 2018, Seattle became the first major city in the US to also ban the use of single-use plastic straws and utensils in restaurants; the city's restaurants will now have to use reusable or compostable options but the ban is intended to move away from the use of straws altogether (CBS News, 2018).

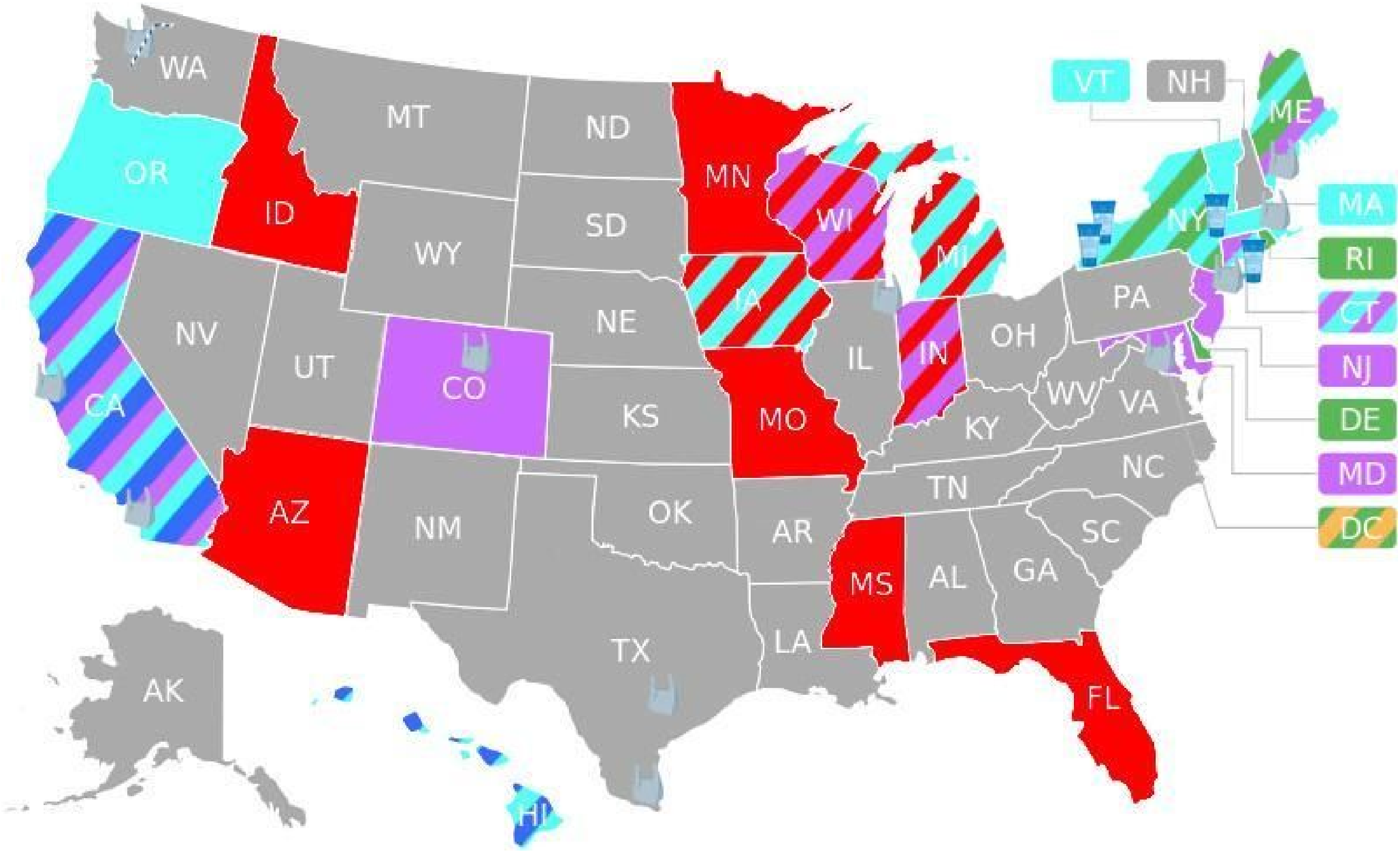
In an effort to tackle primary microplastics, Erie County, NY became the first in the nation to ban microbeads at the local level in 2015. The ban included the sale and distribution of all microbeads, including biodegradable ones, either included in or used to make PCPs with the only exception being prescriptions (NY DOS, 2015). To date it remains the strongest ban on the sale of microbeads in the nation. Since then, four other counties in New York have followed suit and passed their own county level microbead bans including Albany, Suffolk, Chautauqua, and Cattaraugus Counties (Harding, 2015).

State Level

Prior to the national ban in 2015, nine states had passed their own statewide ban on the sale and distribution of microbeads in personal care products. Illinois became the first in 2014 with the other eight following suit in 2015; all bans took effect for the manufacture of PCPs with microbeads in 2018 with the ban extending to the sale or distribution by 2020. Of the nine states, only California also bans the sale and distribution of biodegradable microbeads (Abrams, 2015).

North Carolina has never seen a law banning single-use plastic bags at the state level and with the recent repeal of the Outer Banks Plastic Bag Ban it seems unlikely that one will happen in the near future. Other states in the nation have had more luck regulating this source of secondary microplastics with California becoming the first to introduce a ban on plastic bags unless they are offered at 10 cents in 2014; the state began in 2006 by requiring retail stores that used plastic bags to adopt at-store recycling programs, followed by requiring compostable bags be distinguishable from other bags in 2010 before requiring that any plastic products could not be marketed as compostable or marine degradable without meeting certain standards in 2011. Since then only Hawaii has a de facto statewide plastic bag ban as its most populous counties prohibit non-biodegradable plastic bags and paper bags containing less than 40 percent recycled material at checkout as of 2015. Required at-store recycling programs for plastic bags were first introduced in Maine in 1991 and since then four other states have followed suit, including California, Delaware, New York, and Rhode Island. Recently, 10 states have also seen preemptive legislation introduced for either a ban, tax, fee, or at-store recycling program usually at the local government level (NCSL, 2018).

North Carolina has, in the past, seen three different bills concerning the implementation of a bottle bill introduced into either the house or the senate in 2007, 2009, and 2011; all with the goal of returning the "Clean Roads State" title to North Carolina but all have not made it past initial committees (CRI, 2013). Statewide container deposit laws, commonly referred to as 'bottle bills', are another way states promote recycling and decrease the use of plastic. Bottle bills are implemented as a way to both reduce the amount of bottles littered and conserve natural resources through recycling and the reduction of solid waste entering landfills. Although the first bottle bill in the United States was passed in Oregon and intended solely for beer and soft drinks, today ten states have bottle bills and most have been expanded to include a wide variety of beverages in plastic bottles. Currently over 27.5% of the US population, including the four inhabited territories, live under a bottle bill and a high success rate concerning a reduction of litter has been formally reported in at least seven states (CRI, 2016).



	States that banned single-use plastic bags; HI has a de facto statewide ban
	States that banned microbeads before the 2015 national ban
	Statewide bottle bill
	States with fees or taxes imposed on single-use plastic bags
	Statewide Labeling, Recycling, or Reuse Programs for Single-Use Plastic Bags
	States with preemptive legislation regarding single-use plastic bags
	Cities/Counties that banned single-use plastic bags; not an exhaustive list
	Counties that banned microbeads prior to the 2015 national ban
	Cities that banned plastic straws and plastic utensils; currently only Seattle, WA

Figure 4. *Graphical representation and corresponding legend showing the regional and state level regulations in place to combat microplastics in the United States.*

Country Level

United States

In the wake of multiple states deciding to ban the sale and distribution of microbeads in 2015, along with numerous industries and companies agreeing that there were harmful effects of continued use, the federal government took action quite quickly and by the end of the year the Microbead-Free Waters Act of 2015 was signed into law by President Obama. The law bans the addition of both biodegradable and non-biodegradable plastic microbeads to certain PCPs, namely those classified as 'rinse off' intended to cleanse or exfoliate the body, which exempts cleaning products, other PCPs, cosmetics, and prescriptions that also use plastic microbeads (FDA, 2017). The law banned the production of PCPs with the added plastic microbeads by 2017, the sale of cosmetics containing microbeads by 2018, and the sale of over-the-counter- drugs containing microbeads by 2019 (Trager, 2016).

Back in 2013, the EPA introduced the Trash-Free Waters Program which included set actions to help reduce and prevent the amount of trash entering waterways and marine environments with an overall goal of having zero loadings of trash entering coastal watersheds and ecosystems by 2023. Of the five essential elements of the program, two directly seek to research the effects of plastic pollution and develop a stewardship program specifically for the plastic packaging industry and single-use plastics in general (EPA, 2013). The program also helps to fund various projects across the nation to help cities meet stormwater trash permit requirements as well as host summits and workshops to educate various groups on the harmful impacts of plastic pollution and potential solutions (EPA, 2017).

Other Countries

Like the United States, many other countries have also signed laws that ban the use of microbeads while other have targeted other forms of microplastics or have decidedly stricter laws compared to that of the US. Before the microbead ban in the US was signed in 2015, Austria, Belgium, Luxembourg, the Netherlands, and Sweden issued a joint call for the European Union to ban microbeads in PCPs in late 2014; Canada also made strides by classifying plastic microbeads as a toxic substance nationwide in 2016 (Palmer, 2016). This classification in Canada was followed up by a ban on the import or manufacture of toiletries containing microbeads in January 2018, a ban on the sale of such products in July 2018, and a ban on microbeads in natural health products and non-prescription drugs in 2019 (Gov of Canada, 2018). Also announced in 2016, Australia endorsed a voluntary nationwide phase-out by the industry and stated that should mid-2018 come around with the voluntary phase-out not been effective, the government would move to implement a ban. In 2018 it was determined that 80% of the Australian industry have removed microbeads from their products but it has not yet been announced if the government believes this has been enough of an effort (Tatham, 2018).

In 2017, many countries worldwide announced their intent to ban the use of microbeads including, France (France, 2017), New Zealand (Gov of NZ, 2018), Taiwan (Engbarth, 2017), Sweden (Löf, 2018), and the United Kingdom, all of which took effect in 2018. The UK's ban has been cited as the toughest, most comprehensive ban to date with many calling the UK a world-leader on this issue

(Gov of the UK, 2018). In 2018 the European Union published its Plastics Strategy which included the announcement that the Commission has begun the process to ban both intentionally added microplastics and oxo-degradable plastics (Coquard, 2018). Ireland also announced its intent to ban microbeads in 2017, but the law is not expected to be passed until late 2018 (RTE, 2018), while both India and Italy have bans that will enter into effect in 2020 (Beat The Microbead, 2016).

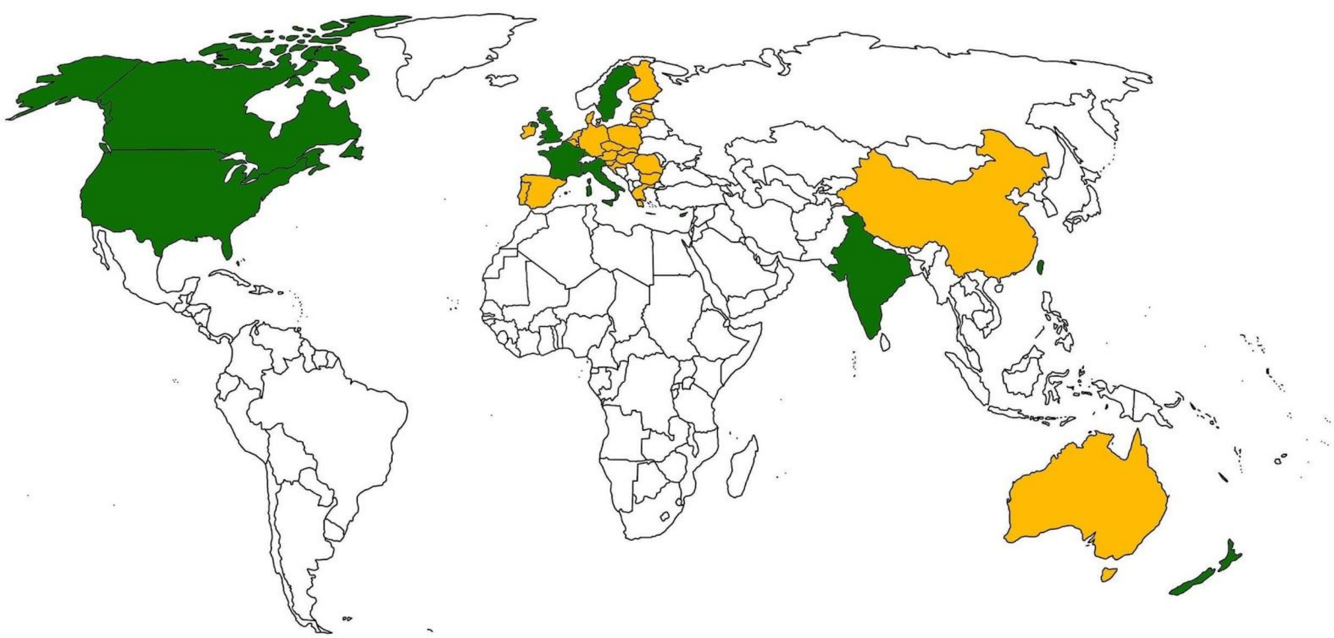


Figure 5. *World map showing the countries that have passed laws banning microbeads that either have entered into effect or will by the year 2020 (shown in green) and the countries that are in the process of banning microbeads but have not been signed into law (shown in orange).*

International Level

Conventions

In 1959 the International Maritime Organization (IMO) met for the first time, ten years after it was established by the United Nations, to regulate shipping. Today, the specialized agency creates regulatory frameworks to both ensure the safety and efficiency of shipping practices as well as the prevention of pollution by ships. As of 2018 there are 173 member states that are subject to the regulations that IMO publishes; the organization is governed by an Assembly and then a Council with a series of Committees carrying out the technical work (IMO, 2018a).

One of the first global conventions to protect the marine environment from the harmful effects of human activities, the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, commonly referred to as the "London Convention" occurred in 1972 and entered into force in 1975 (IMO, 2006); its main goal is to effectively control all sources of marine pollution by taking practicable steps to reduce the dumping of wastes and other matter. In 1996 the London Protocol was agreed upon to modernize the text of the London Convention and eventually replace it; entering into force in 2006 the Protocol made major structural changes and now implements a ‘reverse-list’ approach. Instead of prohibiting the dumping of a certain list of hazards, the 87 state parties must now prohibit the dumping of all waste and other matter that is not listed in Annex 1 of the Protocol; going even further, the dumping of the items listed in Annex 1 also requires a permit (IMO, 2018b). As stated by Annex 1, the dumping of plastics and plastic waste into the sea is prohibited entirely and the only way microplastics would be permitted would be through sewage sludge, dredged material, and material from fishing industry operations.

First adopted in 1973, the International Convention for the Prevention of Pollution from Ships (MARPOL) is currently the main regulatory framework to cover pollution stemming from ships at sea; a Protocol was also adopted in 1978 before MARPOL officially entered into force in 1983 (IMO, 1978). Its goal of preventing and minimizing the pollution from ships extends to both normal operations aboard the ships along with any accidental pollution that may occur; there are six total Annexes of MARPOL that deal with a certain source or type of marine pollution but of note is Annex V. Annex V entered into force in 1988 and its main goal deals with the prevention of pollution by garbage and details the distance from land and the manner in which a variety of garbage types can be disposed of (IMO, 2018c). Although there are some exceptions to what can be disposed of, including food waste, cargo residue, cleaning agents, animals carcasses, accidental loss, and exceptions with respect to the safety of both the ship and those aboard, Annex V explicitly states that all plastics are prohibited for disposal at sea by ships. Within the Annex there are also eight special sea areas which have recognized technical reasons and require the adoption of mandatory methods to prevent pollution by garbage. Although the Annexes are optional, over 150 countries have signed up to voluntarily follow Annex V (IMO, 2018).

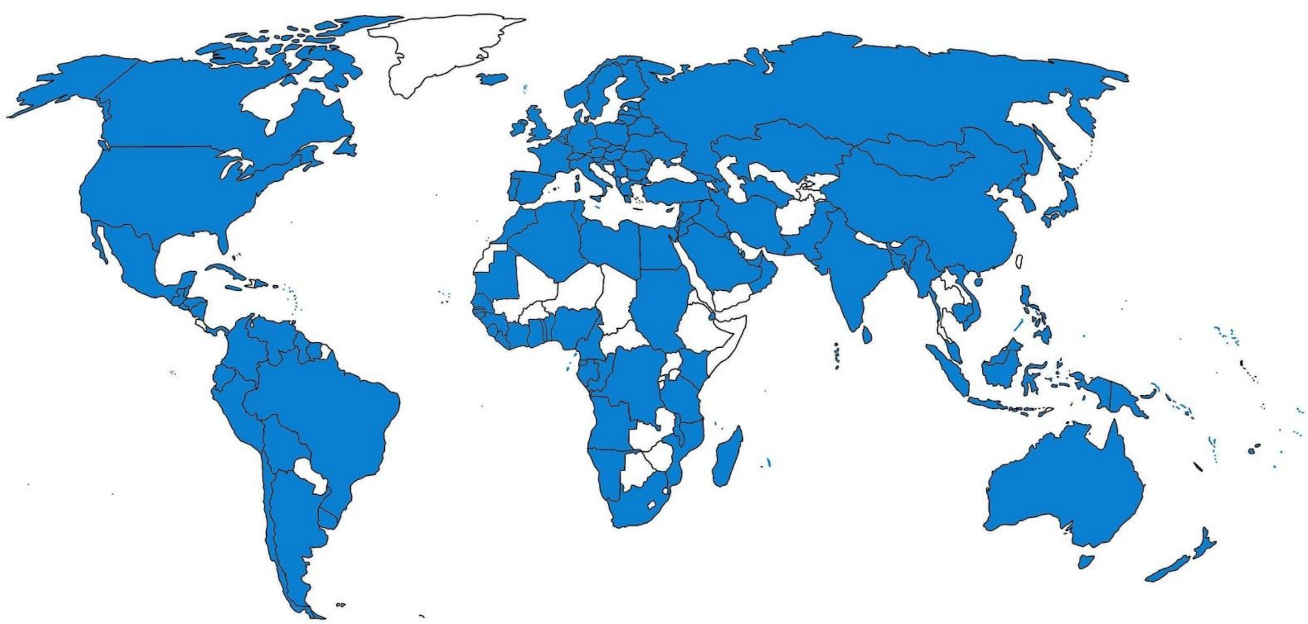


Figure 6. *Countries that have ratified Annex V of MARPOL, shown in blue, which bans all plastics from being disposed of by ships at sea.*

Suggested World Ban

In 2012 the United Nations Environment Programme (UNEP) created the United Nations Environment Assembly (UNEA) after world leaders called on the Programme to be upgraded and strengthened; today the Assembly stands as the "world's highest-level decision-making body on the environment". During its first session in June 2014 the Assembly adopted a variety of resolutions regarding major issues including marine debris and microplastics (Mwangi, 2018). Resolution 1/6 of UNEA recognizes that both marine biodiversity and ocean health are negatively impacted by marine pollution, especially plastics, and notes the Assembly's "commitment to take action to significantly reduce the incidence and impacts of such pollution on marine ecosystems". The main point of Resolution 1/6 was to stress the importance of using the precautionary principle when dealing with plastic pollution, which states that a lack of full scientific evidence should not postpone cost-effective measures to reduce pollution; the Resolution also noted the gaps in knowledge and called for a worldwide assessment on microplastics be completed by the UNEP (UNEP, 2014).

In 2015, that assessment report was completed and released by the UNEP to coincide with World Oceans Day; within the report the recommendation to take a precautionary approach to the issue of microplastics was repeated as well as an eventual phase out of microplastic use in PCPs and cosmetics worldwide (UNEP, 2015). Two years later the United Nations Conference to Support the Implementation of Sustainable Development Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development, commonly known as the "Ocean Conference", was co-hosted by Fiji and Sweden in New York. During this conference, eight countries led by Sweden voluntarily committed to the ban of rinse off cosmetics that contain microbeads by the year 2020 (Hagberg, 2017).

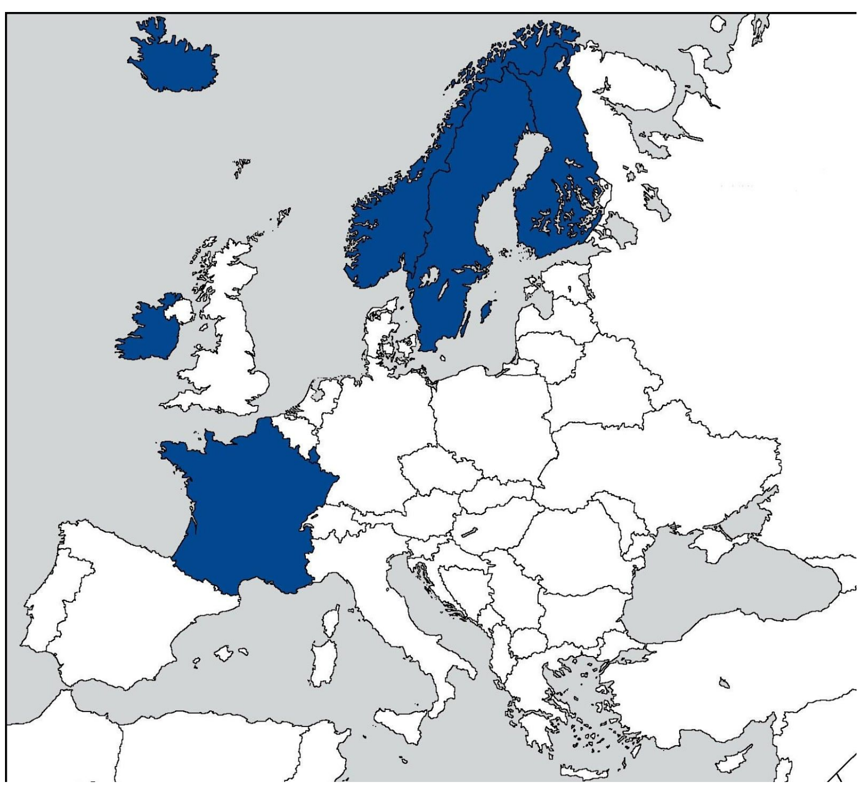


__Figure 7.__ Countries that committed to ban the use of microbeads in rinse off personal care products and cosmetics by 2020 during the Ocean Conference, shown in blue.

International Campaigns

In recent years, as the focus on plastics and microplastics has grown, there have been quite a few international campaigns, initiatives, and art projects dedicated to reducing the amount of microplastics in the ocean.

Although the UNEP did not release its microplastic assessment until 2015, it did sponsor and continues to sponsor the 'Beat The Microbead' campaign and corresponding mobile app jointly created by the North Sea Foundation and the Plastic Soup Foundation. In 2012, five ingredients were the main targets, Polyethylene (PE), Polyethylene Terephthalate (PET), Polypropylene (PP), Polymethylmethacrylate (PMMA) and Nylon, as they were the most commonly used as microbeads in cosmetics and PCPts. The app was developed so that you could snap a picture of a product's barcode and it will tell you whether there were microbeads and other microplastics inside; over the years the app has been updated to include more ingredients known to be used in microbeads and more countries to truly make it a worldwide campaign. The campaign and app have been popular and effective with a number of large multinational companies, such as Johnson & Johnson, subsequently announcing their intent to stop using microbeads (Beat The Microbead, 2017). In recent years, 'Beat The Microbead' has expanded its focus to include more countries, more ingredients, and shift its focus to the companies rather than the consumer; while the app continues to be updated for the consumer, the overall campaign has recognized the importance of holding companies responsible and now when companies make a public statement declaring that none of their products include microplastic ingredients they can place the 'Zero Plastic Inside' logo on all their products to let the consumer know (Beat The Microbead, 2018).

***Figure 8.** From left to right. The icon used for the 'Beat The Microbead' mobile app and the 'Zero Plastic Inside' logo businesses can use if they publicly declare their products are microplastic-free (images taken from the [Beat The Microbead] website).*

In 2017 the UNEP came out with its own campaign called 'CleanSeas' intended to engage governments, consumers, the private sector, etc. in the fight again marine plastic litter. Its goal is a five year plan focusing on the production and consumption of non-recoverable and single-use plastics, their main use is as a platform that others can use to engage and stay informed; they post news updates about individuals and companies taking steps towards reducing microplastic pollution using #CleanSeas to bring public awareness on social media (UNEP, 2017). The biggest part of the campaign lies in the pledging process where individuals, companies, NGOs, groups, and governments can pledge any or all of their six promises in an effort to reduce plastic consumption; pledges can include avoiding products with microbeads, saying no to straws, and remembering reusable bags. The campaign currently has 98,000+ pledges, 44 governments on board, and over 10 companies committed to the goal (UNEP, 2017a). At a smaller scale, Operation Clean Sweep is dedicated to reaching plastic companies and their employees in the fight against microplastic pollution stemming from the production of macroplastics. The overall goal is working towards achieving zero pellet, flake, and powder loss; both the company overall can pledge to reduce accidental loss, as well as individual employees with organizations that do not qualify for the pledging process as they do not handle plastic pellets, can still become supporters of the campaign. The campaign has been around for 25+ years with over 200 companies across the world having taken the pledge (American Chemistry Council, 2018).

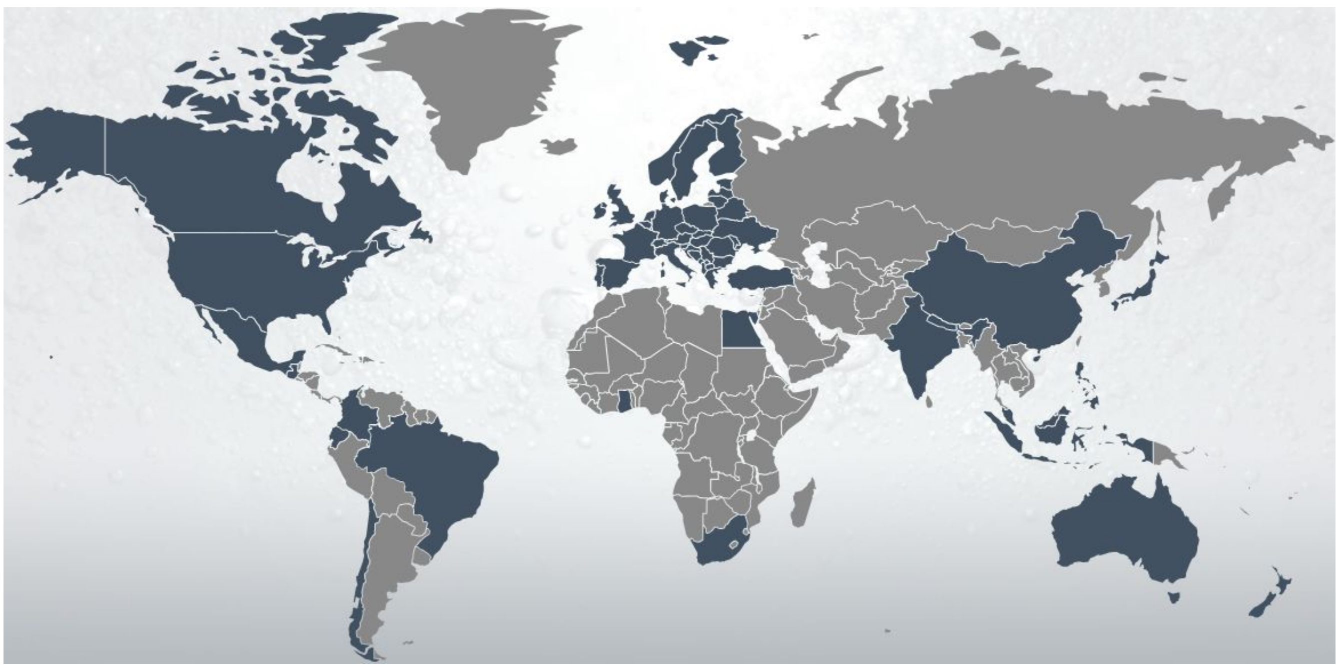


Figure 9. *World map showing the countries where companies that manufacture or handle plastic pellets have pledged to be partners in the Operation Clean Sweep campaign, shown in blue (image taken from the Operation Clean Sweep website).*

A variety of initiatives and art projects have worldwide reach through the internet and focus more on engaging the consumer, either by educating them on the harmful effects of plastics and microplastics or by having them take action. In 2013, at the United Nations Educational, Scientific, Cultural Organization (UNESCO) in Paris, Italian artist Maria Cristina Finucci debuted the 'Garbage Patch State'; a transmedia, environmental artwork piece comprised of videos, performances, and installations to bring awareness to the garbage patches in every ocean gyre that collect plastic. Although these garbage patches often go unnoticed, due to their distance from land or the plastic degrading into small, invisible particles, in total there is about 16,000,000 square kilometers of garbage patches covering the earth; the ongoing art piece is intended to bring awareness to the issue by giving recognition to the patches both in the oceans and on land. In 2013, at the same Paris UNESCO where the art piece began, UNESCO also declared the garbage patch a federal state, now called the Federal State of Garbage Patch, with its own flag, birth registry, embassy, etc. in order to highlight just how big the problem was. Since 2013 there have been 11 art installations across the world to showcase the plastic problem and bring attention to the 'Garbage Patch State' (Finucci, M.C., 2018). Also looking to bring awareness while taking action, in 2017 the company 4Ocecan was founded by two surfers who had traveled to Bali and saw the amount of plastic covering the beaches. The company sells bracelets made entirely from recycled materials and at $20 USD each one funds the removal of one pound of plastic from the ocean and coastlines. To date, over 1 million pounds of trash have been removed through this method and the company works in both the US and Bali to make the bracelets, host clean ups, and educate consumers on the dangers of plastic (4Ocean, 2018). Another initiative known as 'Run for the Oceans', began as a collaboration between adidas and Parley Ocean Plastic Program and hosted by the mobile app Runtastic. Kicking off on World Oceans Day, the entire month of June runners could log their kilometers with the goal of running a total of 1,000,000 km at which point adidas would donate $1 million USD to Parley to help support their Parley Ocean School, which brings the next generation into the oceans to better educate them and better prepare them for future marine conservation. At the end of June 2018 over 12 million km were logged and the initiative has continued with runners encouraged to continue logging their kms and fundraising on their own (Parley, 2018).

Figure 10. *From left to right. The official flag of the Federal State of Garbage Patch (image taken from [ARTE.it]); the bracelet 4Ocean sells to remove plastic from the ocean (image taken from [4Ocean]); logo for the Run for the Oceans initiative by adidas and Parley (image taken from [Parley]).*

What Solutions Already Exist?

Washing Machine Additives

As the microplastics pollution problem has gotten more public attention, there have been small entrepreneurial companies coming out with products to help combat the issue at the consumer level. Though products have only recently been developed and are available to the general public, in the past three years two have come out: the Cora Ball and the GUPPYFRIEND. Both products made their debut on Kickstarter to be publicly funded within a year of each other around 2017 and both are intended to be used in laundry to collect microfibres. The GUPPYFRIEND was first developed in Germany by owners of Langbrett, a surf gear and outdoor apparel company, who were deeply troubled when they first learned of the plastic pollution generated by washing synthetic clothes (O'Connor, 2017). The GUPPYFRIEND is a nylon mesh bag with holes small enough to let soap and water in while preventing microfibres from being flushed out; synthetic clothes are simply washed in the bag and upon removal the microfibres stuck to the inside of the bag can be scraped off and properly discarded (STOP! Micro Waste, 2018). After the initial project was launched on Kickstarter in late 2016 it took only two months to reach its goal to begin production and now the company has partnered with outdoor clothing company Patagonia to begin selling them online and in stores (Patagonia, 2018). Just a short while later in early 2017, another project known as the Cora Ball was also launched on Kickstarter and managed to surpass its goal in three hours (Rozalia Project, 2017). Developed by the Rozalia Project in Vermont, the Cora Ball is a reusable, recyclable laundry additive made from recycled plastic and designed with coral in mind to help catch microfibres that are released from all types of clothing during wash; after the wash the microfibres can be taken from the stalks of the ball and properly disposed of (Cora Ball, 2018).

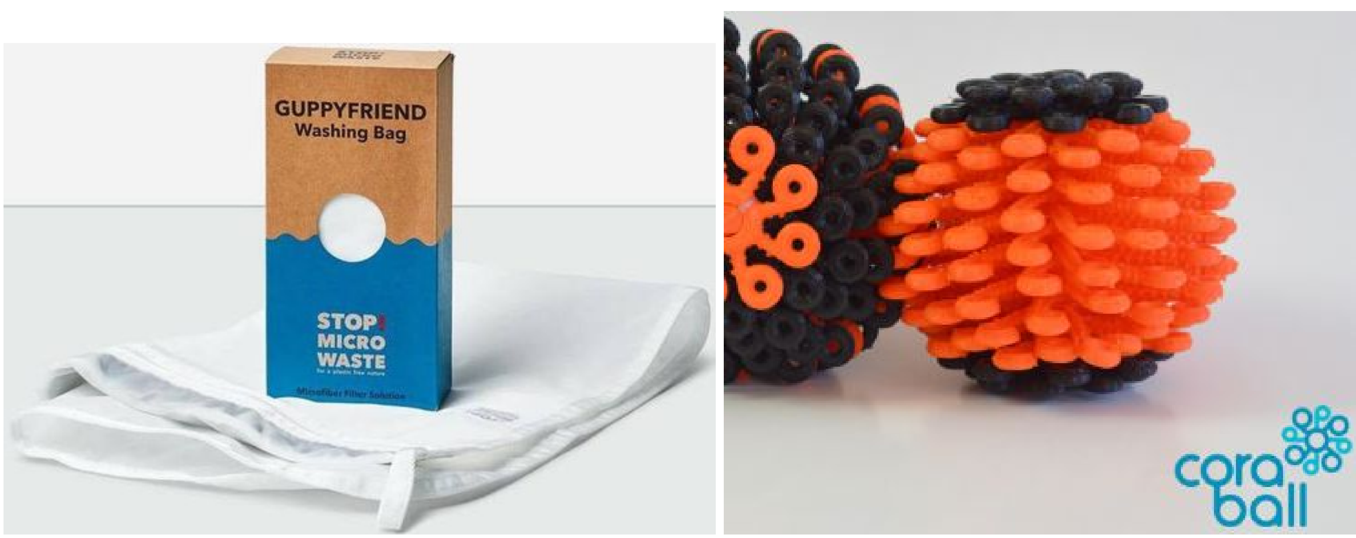


Figure 11. *Photos from left to right of the GUPPYFRIEND (image taken from Patagonia) and the Cora Ball (image taken from Reef Divers)*

A more expensive option comes in the form of a lint filter for washing machines which several companies have begun developing to also catch microfibres. Many washing machines do not come with filters incorporated into their design and those that do are usually there to keep larger items like coins out of the system. As a result, a few companies in at least Canada and the US have developed lint filters to combat microfibre pollution; these filters are designed to be externally attached and the effluent from each wash passes through the filter before entering the septic system (Environmental Enhancements, 2018). Although this consumer option is more expensive, the filters are marketed for households on city sewers or personal septic systems and as not only helping to keep microplastics out of the septic systems but also lint, sand, pet hair, etc. These more common sources of dirt have long been known to clog sewage drains and cause septic system failure, now the knowledge that microplastics can also cause these problems is becoming more well known (Wexco Environmental, 2018). Companies like Environmental Enhancements in Nova Scotia, Canada and Wexco Environmental in Minnesota have similar designs where the effluent discharge from the washing machine is rerouted to pass through a screen before being discharged into the septic system through the normal drainpipe; in both instances, the screens have small enough holes to catch microplastics, are made of either steel or nylon, and can be hand-washed when visibly obstructed to properly dispose of the microplastics and other dirt (Environmental Enhancements, 2018).

Figure 12. *From left to right, the Filtrol 160 lint filter from Wexco Environmental retails at $152 (image taken from [Wexco Environmental]) and the Lint LUV-R washing machine discharge filter from Environmental Enhancements retails at $140 (image taken from [Environmental Enhancements]).*

Faucet Filters

With recent studies coming out with evidence to suggest microplastics are found in 93% of bottled water worldwide and 94% of tap water in America, homeowners can do their part to reduce their microplastic consumption by reducing the amount of bottled water they consume and purchasing a faucet filter. Currently there are four types of faucet filters in existence that are capable of filtering out microplastics, Granular Activated Carbon (GAC), Carbon Blocks, Reverse Osmosis, and Ion Exchange filters. GAC filters are made using raw organic materials that are high in carbon, such as coal or coconut shells, and use heat to increase the surface area of the carbon thus activating it. The activated carbon can then remove certain chemicals or microplastics down to 5mm by absorbing them into the GAC; these filters require proper installation and periodic maintenance as the GAC needs to be changed based on contaminant levels and water use. GAC filters can either be installed for the whole house to covers all faucets or as point of use filters right before the faucet, such as under the sink or in refrigerators; most are installed as pairs to ensure that anything getting past the first is trapped by the second (MN Dept. of Health, 2018). Ion exchange filters are generally used as a preliminary step before reverse osmosis at which point 90-99% of all contaminants can be removed from the water, down to 0.001mm, using high pressure water flow passing through a semipermeable membrane. Due to its high efficiency many large corporations and companies use this method but means that the installation and maintenance is often too expensive for the average consumer (APEC, 2018). Carbon block filters are much the same as GAC filters in how they work and only differ in that the carbon is in a very dense block; due to the tighter structure most carbon blocks are able to filter down to 2mm and are often marketed as tap filters in their small design. A recent product, TAPP 2, has come out as one such carbon block filter and is marketed as both affordable and the first of its kind with biodegradable carbon refill cartridges (TAPP WATER, 2018).

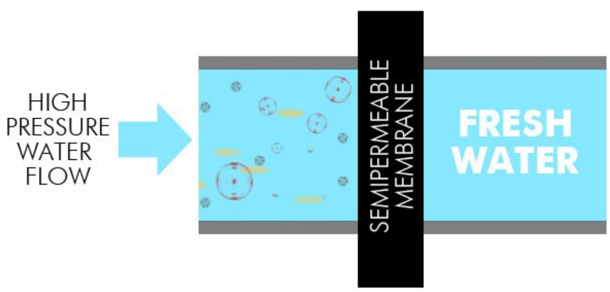


Figure 13. *From left to right. A typical whole-house GAC filter (image taken from the Minnesota Department of Health); the process of reverse osmosis (image taken from APEC); the TAPP 2 product (image taken from TAPP WATER).*

Advanced Wastewater Treatment

At the city level, one way to combat the amount of microplastics entering the waterways would be to upgrade the current wastewater treatment plants. Many wastewater treatment plants have one round of treatment which results in primary effluent while some have two rounds of treatment resulting in secondary effluent; these rounds of treatments are designed to target major pathogens and excess chemicals so that the effluent released into rivers does not negatively impact the ecosystem.

Additionally, those treatment plants that serve to produce potable drinking water will normally have additional stages of treatment most commonly involving an additional filtration and then UV treatment. Wastewater treatment plants were not originally designed with microplastics in mind and therefore many are not capable of filtering out these small plastic particles; this results in a negative environmental impact as microplastics have been found as far as 2km downstream of a treatment plant, at which point many have been incorporated into river ecosystems and those that are not often get transported out into the ocean (Hoellein, Kelly, & McCormick, 2016).

The process of using a conventional activated sludge (CAS) system as a second round of treatment is a widely common practice in both municipal and industrials treatment plants; a CAS system involves the primary effluent pumped into an aeration tank where oxygen is added to activate micro-organisms which will clump together in flocs while digesting the wastewater, the effluent is then pumped to a clarifier where the flocs will settle out to be disposed of and the remaining water will be the secondary effluent either disinfected and discharged or passed to a tertiary treatment (One V Project, 2016). Studies have shown that while this system can remove up to 99% of microplastics, the remaining 1% of the effluent is still a significant source of microplastic pollution due to the amount of effluent a typical wastewater treatment plant discharges in a day. A Swedish study looked into five different types of effluent treatments to determine which would be the best at removing more microplastics; the top treatment was a membrane bioreactor (MBR) at 99.9% effective followed by a rapid sand filter (RSF) at 97% effective, dissolved air flotation (DAF) at 95% effective, and a disc filter at 40-98.5% effective depending on filter size (Talvitie, Mikola, Koistinen, & Setälä, 2017). The MBR was the only secondary treatment and is a version of the CAS system where the primary effluent is first sent through both an anoxic and aerobic holding chamber before entering the aeration tank where microfiltration membranes are coupled with a suspended growth bioreactor, whereas in a traditional CAS system the aeration and clarifying process are separated (Judd & Judd Ltd, 2018).

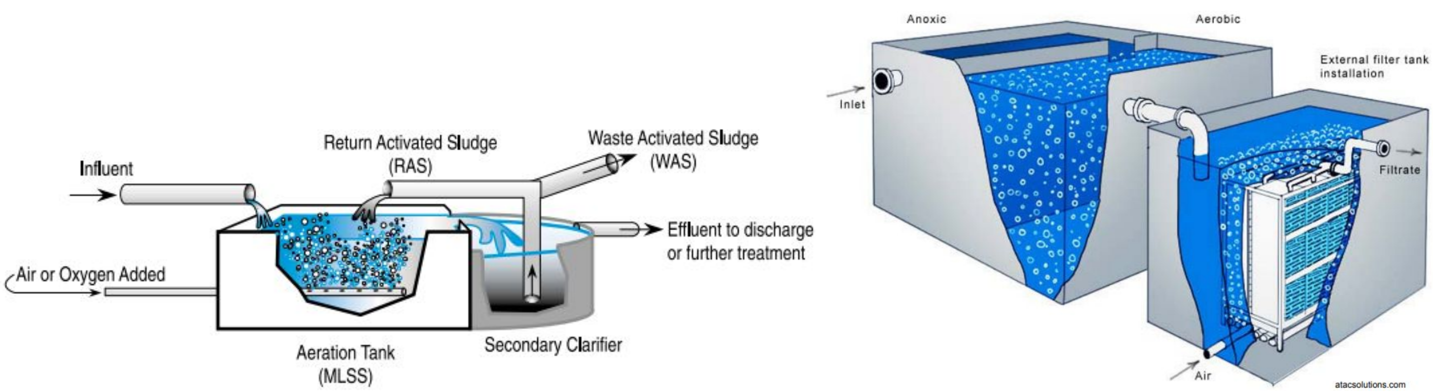


Figure 14. *Left to right. Diagram of a typical CAS system (NESC, 2003). Diagram of a MBR (Talvitie, 2017).*

RSF, DAF, and disc filters are all tertiary treatments that tackle secondary effluent. The RSF is commonly used in municipals for drinking water and uses gravity to trap impurities in the wastewater within sand; despite its effectiveness the systems are usually very costly to both maintain and operate. A DAF system is much like a simplified CAS system where the secondary effluent is pumped into a tank along with oxygen; the bubbles of oxygen will attach to the suspended matter and float it to the surface where a skimming device removes it (JWC Environmental, 2018). Disc filters use multiple discs with individual filter cartridges to trap impurities in the water; this system is highly effective at processing large amounts of wastewater but its effectiveness at removing microplastics depends on the filter size used within the discs (Wes Tech, 2018).

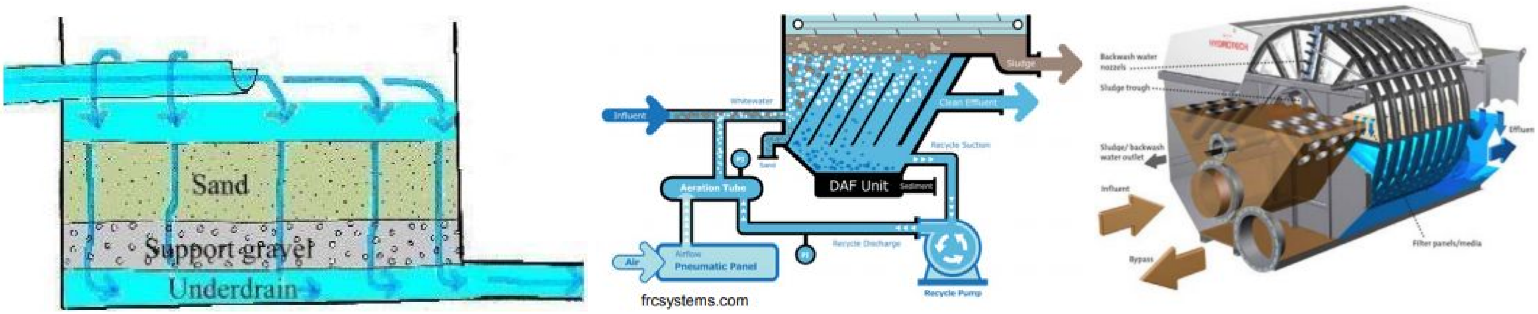


Figure 15. *Left to right. A Rapid Sand Filter, Dissolved Air Flotation, and Disc Filter system (Talvitie, 2017).*

Plastic Alternatives

The most obvious solution to the amount of plastic consumed and used throughout the world, and therefore the amount of microplastic produced, is to use less. The introduction of plastic revolutionized the modern world but mounting evidence has shown that most plastic products have unintentional environmental and health consequences and that proper disposal to avoid these are not yet capable by a majority of the world. Fortunately, a small growing population has begun developing and popularizing the use of plastic alternatives from the business level to the consumer level. A variety of businesses have begun phasing out the use of plastic straws by redesigning drink lids as well as offering compostable utensils for take out instead of traditional plastic or biodegradable plastic. Many grocery stores have also been more prominently advertising the purchase of branded, reusable bags while fast food joints have come out with branded, reusable drink containers, often with a discount for future drinks. At the consumer level, the advertisement for plastic alternatives is not always as big as the amount of products available but there are countless natural fibre clothing; stainless steel drink containers; organic, reusable food wraps; biodegradable trash bags; glass baby bottles; etc.

Figure 16. *From left to right, Starbucks new drink container lids designed to eliminate the use of straws (image taken from [Starbucks]); one design of compostable utensils (image taken from [Green Home]); one type of reusable grocery bag (image taken from Amazon)*

What Should Be Done?

Policy Recommendations for North Carolina

North Carolina would do well to follow in the footsteps of other states to combat microplastics at the sources such as adding a ban or fee to things like single-use plastic bags and water bottles. As seen previously, the Outer Banks had a plastic bag ban in place for almost a decade before its repeal last year and while that specific case had conflicting studies as to if/how much the ban helped to decrease plastic bags on the shores, other cities still have plastic bag bans in place with studies that show that both the use of plastic bags as well as the amount found in nearby rivers, waterways, and marine environments decreased significantly. One of the reasons some conservative politicians sought to repeal the ban was because it only affected 3 counties and was not statewide; despite this, a statewide ban seems unlikely with the recent Outer Banks ban repeal and the conservative majority in the North Carolina General Assembly. Another way to promote recycling and decrease the use of plastic would be to implement a container deposit law, commonly referred to as a 'bottle bill', for plastic bottles. With almost half a century of successful bottle bills in the US, North Carolina would be in good company to also enact a bottle bill and has made progress in the past; three different bills have been introduced into either the house or the senate in 2007, 2009, and 2011 all with the goal of returning the "Clean Roads State" title to North Carolina but all have not made it past initial committees (CRI, 2013).

Other than banning secondary microplastics, the state could also implement or incentivize the use of better filtration to take microplastics out of waterways. As most current wastewater treatment plants do not have the capacity to filter microplastics, upgrading the facilities to have tertiary treatment stages in order to filter out microplastics would be the most direct way the state could make a positive impact on the reduction of microplastics. Taking into account that adding tertiary treatment stages is quite costly, the state would do well to either target major cities or coastal cities to either require these be added or incentivize the cities to do so. Bringing the scale down, the state could also focus its efforts on homeowners and businesses by either requiring laundromats to install a microplastic filter or incentivizing both the laundromats and homeowners perhaps with the addition of outreach materials explaining the benefit of a microplastic filter and the low cost investment needed.

Campaign Strategy for the North Carolina Coastal Federation

The North Carolina Coastal Federation has done great work in the past regarding other environmental issues and is in a great position to do so again concerning the microplastics issue. The Coastal Federation has five main priorities which it structures its actions and contributions around, one of which being marine debris; the marine debris priority centers around reducing the overall amount found on North Carolina coastlines through education, organizing cleanups, advocation, and the development of a coastwide strategy (NCCF, 2018). Although microplastics are included in the definition of marine debris used by the Coastal Federation, there is currently little distinction made between microplastics and other marine debris in general, especially fishing gear which is a major concern within this priority. It would do well to separate out microplastics as a focal point to the marine debris priority in the same way that fishing gear is currently, this should then be coupled with the same education and advocation efforts currently seen but more prioritized. An effort should be made to develop educational workshops, educational talking points, and outreach materials specifically focused on microplastics that can either stand alone or attach to current marine debris educational efforts to bring more awareness to this growing issue. Advocation should also be a main effort point by the Coastal Federation to combat microplastics, the organization is already present in North Carolina policy efforts and in the future should support legislation that focuses on better filtration efforts, natural products over synthetic products, scaling back the use of single-use plastic items, etc. The current marine debris strategy plan being developed by the Coastal Federation for the state of North Carolina has a small section dedicated to explaining microplastics but this should either be expanded upon or a separate document for microplastics should also be developed. All of these efforts would fall in line with what the Coastal Federation is currently doing with the added effort of distinguishing microplastics to highlight their environmental impact.

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