

Technical Review of Microbeads/Microplastics in the Chesapeake Bay



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Executive Summary

Recent estimates indicate that there are trillions of pieces of plastic floating at or near the surface of the world's oceans, and that the majority of this pollution is microplastic (less than 5 mm in size). Like larger items of plastic debris, microplastic has been reported in nearly all aquatic habitats, from the surface to the depths of every major open ocean and in freshwater lakes and rivers. The small size of microplastic makes it bioavailable to a wide range of species of aquatic animals, across nearly all sizes and trophic levels. Recently, one source of microplastic debris has received much attention in the media and from policy makers: synthetic plastic microbeads.

This review panel was originally tasked to write a report describing the scientific evidence regarding plastic microbeads as it relates to microplastic contamination in general and in the Chesapeake Bay in particular. In the interim, federal legislation to ban microbeads, the Microbead-Free Waters Act, was signed by President Obama on December 28, 2015. While laudable in its intent, the Act leaves much to be desired for microplastic mitigation. The Microbead-Free Waters Act (i) does not mitigate all sources of microbeads to aquatic habitats (i.e., only applies to rinse-off personal care products), and (ii) is restrictive when it comes to potential innovative technological solutions (i.e., may prevent use of any new types of plastic microbeads in some applications, even if they are environmentally benign). Accordingly, future legislation and regulation, whether concerning microbeads or other sources of microplastics, should more carefully address these issues.

Due to the original tasking, this report emphasizes microbeads. However, because microbeads are not the only source of microplastic contaminating local habitats, this report's scope has been broadened to include information regarding microplastic in general.

Fate & Transport

What is the proper definition of 'degradable' in regard to microbeads in the aquatic environment, and what factors impact degradability and rate of breakdown? There is a need for clarity when using the terms *plastics*, *microplastics*, *microbeads*, *degradable*, and *biodegradable*. "Plastics" refers to moldable polymers of high molecular weight that can be made into objects of different shapes, including beads, films, or filaments. In common usage, this word is limited to *synthetic* polymers of anthropogenic origin, but some naturally-occurring polymers can behave as plastics. "Microplastics" refers to pieces of synthetic plastic less than 5 mm in size. "Microbeads" refers to synthetic plastic particles that are roughly 5 μ m to 1mm in size. "Degradability" refers to the ease with which an organic substance enters the natural carbon cycle. A substance can be *degradable* because it is *biodegradable* or because it is subject to non-biological degradation. A material is biodegradable if it is subject to enzymatic cleavage of the polymer bonds and the resulting breakdown products enter the natural carbon cycle. Non-biological degradation, such as photolysis, can also break polymer bonds and generate breakdown products that enter the natural carbon cycle. Factors influencing rate and extent of degradation include particle size and shape, the nature of the polymer and additives, presence or absence of light, types of microorganisms in the environment, oxygen, salinity, temperature, and pH. Legal definitions and standards for degradability/biodegradability are needed for critical environments where microbeads/microplastics are likely to be present and persist, such as anaerobic/anoxic/aerobic wastewater bioreactors, anaerobic digesters, seawater surface layers, and the guts of aquatic organisms. A quantitative metric of degradability should ideally set clear endpoints such as conversion of a percentage of the material to CO₂ within a given amount of time, or the extent of degradation within a specified time frame relative to naturally-occurring reference materials, such as cellulose or PHB (poly (3-hydroxybutyrate), a biodegradable biopolymer that is moldable and has no known negative impacts on ecosystem health. Use of reference materials could also have value for

ecotoxicology assessments. Development and adoption of appropriate standards based on such definitions could provide environmental protection and allow for materials innovation.

Is there a concern that contaminants from the water can adhere to synthetic plastic microbeads?

Yes, microbeads, and plastic debris in general, accumulate chemical contaminants (e.g., persistent organic pollutants (POPs), algal toxins, and metals) from the surrounding water. The nature of both the polymer and contaminant controls the extent of sorption. Other factors, such as weathering and biofouling may also affect sorption. Biological organisms will also grow on plastics, which can be considered contaminants when they are hazardous (e.g., *Vibrio*).

What is the potential geographic range of impact, i.e., is their impact quite local (like sediment) or does their buoyancy allow them to travel great distances (more like air)? Microbeads and microplastics are likely found at greater concentrations near their sources, such as urban watersheds. Still, the range of geographic impact is widespread. Contaminated areas include fresh, estuarine and marine surface waters and sediments. The buoyancy of microplastics plays a role in transport. Biofouled and negatively buoyant plastics concentrate in sediments. In addition, environmental characteristics such as currents and wind will affect transport and can possibly carry both plastics and hitchhiking organisms long distances. Thus, plastics may act as vectors for introduction of non-native species (e.g., the arrival of Asian species to the U.S. West Coast following the Japanese tsunami).

Potential Impact

At this time, there is insufficient information regarding impacts from microbeads on aquatic organisms. However, the scientific literature regarding impacts from microplastic in general is growing and can inform how different types of microplastic debris, including microbeads, may affect wildlife.

Are there physical impacts of microplastic to aquatic organisms? Yes, but the number of studies to date investigating the physical effects of microplastics in natural environments is inadequate. Urgent research needs exist in the ecotoxicology of microplastics, including microbeads.

Is there a risk that synthetic plastic microbeads, both with and without sorbed contaminants, could serve as a vector to aquatic organisms? Yes, via two pathways: 1) Microbeads may leach previously sorbed chemical contaminants into the environment exposing wildlife through water, particulate matter, or the food chain; 2) Chemical additives or chemicals that accumulate on plastic microbeads may transfer to an animal upon ingestion. This report cites several laboratory and a few field studies that demonstrate how microbead-like microplastics (i.e., microplastics of similar type, size, and shape as microbeads) can serve as a source of chemicals to aquatic animals.

What is the evidence of bioaccumulation and is it worse in certain types of species such as mollusks, filter feeding forage fish, etc.? Microbead-like microplastics have been documented in many species of wildlife across multiple trophic levels and habitat-types. One might hypothesize that organisms that filter large volumes of water would exhibit greater accumulation potential. At present, however, the panel knew of no controlled experiments that document species-specific accumulation potential.

Is there a risk that synthetic plastic microbeads that have sorbed contaminants could serve as a significant health risk for humans? Microplastics are ingested by animals that we consume as food, including bivalves (e.g. oysters and mussels) and fish. Microplastic has also been detected in food staples such as sea salt. Still, impacts on human health are undefined due to lack of study.

Are there any research findings on microplastics specific to the Chesapeake Bay and its tributaries? Data are extremely limited to date. Nonetheless, Yonkos et al. (2014) recently reported the presence of microplastic in four tributaries of the Bay (i.e., the Patapsco, Rhode, Corsica and Magothy Rivers). Concentrations correlated positively with human population densities and extent of urban/suburban development within the watersheds. Highest levels appeared after rain events, suggesting runoff is likely a major contributor. Rochman (personal communication) sampled final effluents from three wastewater treatment plants (WWTPs) in Maryland. Data have yet to be analyzed, but microplastics are apparent in some samples.

Treatment

What is the expected removal of microbeads/microplastics in conventional wastewater treatment facilities in the Chesapeake Bay watershed? What are the removal mechanisms? What is the fate of the microbeads/microplastics? Most conventional WWTPs include primary clarifiers as an initial process that allows particles to settle by gravity or float to the surface for removal. Primary clarifiers are expected to remove a large portion of microbeads in the size range of 20-500 μm , with more effective removal of larger particles. The vast majority of all conventional WWTPs include some form of biological treatment as the secondary step. Most persistent plastic (e.g., polyethylene, polypropylene) microbeads and microplastic in the size range of 20-500 μm would not be expected to biodegrade within the residence time (typically 2-30 days) of the biological solids, and will therefore be removed and transferred to the solids handling processes. Tertiary filtration, when present, would have a typical expectation of 90% removal of 10 μm and larger particles, and these particles would also indirectly enter the solids handling processes. Previously captured microplastics are likely to be reintroduced into terrestrial systems when solids removed by treatment are applied to land. The fate and consequences of these releases are currently unknown, but there is potential for further input of microplastic to aquatic habitats via runoff.

What is the extent of microbead/microplastic discharge from combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs)? Discharge of untreated sewage from CSOs and SSOs during wet weather events would result in direct transfer of microbeads to water bodies, but discharge of raw sewage from CSOs and SSOs has become a much less significant concern in recent years and this concern should continue to decline over time.

Are there emerging technologies that could enhance removal of microbeads/microplastics? What is the potential for the implementation of these emerging technologies? A few advanced WWTPs, that are focused on providing reuse water for potable applications also include membrane microfiltration and ultrafiltration processes. These processes would be expected to provide almost complete removal of particles, but at great expense. Source control solutions based upon standardized metrics for degradability could encourage innovation, while protecting the environment.

What would be the expected removal of microbeads/microplastics in conventional drinking water treatment plants using surface water supplies? Is additional treatment warranted? There is minimal concern for the presence of microbeads in the public water supply.

Does it make sense to place most of the burden of microbead/microplastic control on WWTPs? No, upstream management of microplastic is most efficient.

Potential Urgency

Is there any evidence of the direction of potential impact, i.e., are microplastics being seen in increasing quantities at local or regional scales? Microplastics have been detected in increasing

quantities in the environment and over greater regional areas. Recent studies have found microplastics in local watersheds of the Chesapeake Bay. Without plans for future mitigation, contamination will likely increase.

Is this really a problem that rises to the level of taking individual state action? That is, is this having an impact (or is this likely to have an impact) on the Chesapeake Bay and its tributaries? Microplastics and microbeads are both present in the Chesapeake Bay. Studies measuring their abundance and ecological impact in the Chesapeake Bay are still in their infancy. Still, information relevant to microplastics in general is relevant to the Chesapeake Bay.

Microbead-Free Waters Act of 2015

What is beneficial about the federal legislation banning microbeads? The 2015 federal legislation is beneficial because it publicized the issue of persistent plastics in the environment and removes one of several sources of microplastics to aquatic habitats. It is an important first step and indicates broad consensus among legislators, industry, scientists, and environmental advocates that microplastics in general and microbeads in particular may pose unacceptable risks to the environment. However, it must be understood that microbeads are a subset of microplastics. Elimination of microbeads alone does not eliminate the greater microplastics problem.

Does the language in the bill allow for novel innovative scientific solutions now and in the future? The wording of the Microbead-Free Waters Act prohibits certain innovative scientific solutions that are potentially cost-effective, environmentally benign, and acceptable to consumers. The Act prohibits “the manufacture and introduction or delivery for introduction into interstate commerce of rinse-off cosmetics containing intentionally-added plastic microbeads”. Plastic microbeads are defined as “any solid plastic particle that is less than five millimeters in size and is intended to be used to exfoliate or cleanse the human body or any part thereof”. Accordingly, the legislation actually would prevent current and future innovative solutions that utilize plastics that may be safe and truly degradable.

Introduction

Recent estimates indicate that there are more than 5 trillion pieces of plastic floating at or near the surface of the world's oceans, and that the majority of this pollution is microplastic (less than 5 mm in size; Eriksen et al. 2014). Microplastics have emerged as a contaminant of concern and a critical management challenge in a number of waterways across the United States as evidence of widespread occurrence, significant loadings, and harmful impacts to aquatic life comes to light. Microplastics originate from numerous sources including microfibers from synthetic clothing, microbeads in household cleaners, cosmetics and personal care products, and the breakdown of larger plastic litter such as Styrofoam, plastic bags and wrappers, and cigarette butts. Like larger items of plastic debris, microplastic has been reported on the surface of every major open ocean (Van Sebille et al. 2015), in the deep sea (Woodall et al. 2015) and in freshwater lakes and rivers (Eriksen et al. 2013; Castañeda et al. 2014). Microplastics have even been reported in Arctic sea ice (Obbard et al. 2014). The small size of microplastic makes it bioavailable to a wide range of species of aquatic animals, across nearly all sizes and trophic levels. Recently, one source of microplastic debris has received an especially large amount of attention in the media and from policy makers: synthetic plastic microbeads.

Microbeads are synthetic polymers produced for a variety of products. They range from roughly 5 μ m to 1mm in size. For comparison, the diameter of a human hair is roughly 80 μ m. They are made from synthetic polymers, including polyethylene, polylactic acid (PLA), polypropylene, polystyrene, or polyethylene terephthalate. They are used in a multitude of products, particularly as abrasive scrubbers (including face wash, body wash, cosmetics, and household cleaning supplies), and are used as a replacement for natural exfoliating materials, such as pumice, oatmeal, apricot, or walnut husks.

Many microbeads are designed to be rinsed-off and/or discarded down the drain. Due to their small size, microbeads can escape into the environment via final treated effluents or biosolids (sewage sludge) from waste water treatment plants (WWTPs), the degree to which depends on the specific liquid and solids treatment processes employed at a given WWTP (Rochman et al. 2015a). As a consequence, microbeads have become one of the many types of microplastic debris reported in aquatic habitats (Eriksen et al. 2013; Castañeda et al. 2014). The simplicity of removing them from products and replacing them with natural alternatives has made microbeads the “low hanging fruit” for regulation, with ban on production and sale providing a simple solution to combat one of the many sources of microplastic pollution.

As of Fall 2014, a number of companies were voluntarily removing microbeads from their products, eight states had passed laws to ban manufacture and sale of products with microbeads, and active discussion was underway on federal regulation to control or ban microbeads. It was within this context that the Chesapeake Bay Commission (CBC) requested the Chesapeake Bay Program's (CBP) Scientific and Technical Advisory Committee (STAC)'s assistance in determining whether a course of legislative action was appropriate. In response to this unique request for a direct connection between science and policy, STAC designed a unique process for conducting the review, wherein the questions structuring the review were initially developed via a collaborative process between the scientists and members of the CBC and additional state legislators. This ensured that the resulting report would be helpful in deciding if legislative action was appropriate, since it directly identified aspects of the issue that required scientific input. Thus, the report is structured as responses to specific questions in the general areas of fate and transport, impact, treatment, and urgency of intervention.

This review panel was originally tasked to write a report describing the scientific evidence regarding plastic microbeads as it relates to microplastic contamination in general and in the Chesapeake Bay in particular. During the writing of the report, federal legislation to ban microbeads, the Microbead-Free Waters Act, moved quickly through the Senate and was signed by President Obama on December 28, 2015. The panel notes that the new federal legislation does not prevent all plastic microbeads from entering aquatic habitats, and that microbeads are only one source of microplastics to the Chesapeake Bay. Consequently, the panel broadened its scope of work to provide more information about the new legislation and microplastic debris in general. Passing of the Act also presented a unique opportunity to examine the importance of language and scientifically-based definitions in legislation, make recommendations to improve its effectiveness, and potential mechanisms for expanding its protection. Thus, the review is able to make recommendations that apply both to future legislation at the federal and regional level.

Fate and Transport

What is the proper definition of ‘biodegradable’ in regard to microbeads in the aquatic environment, and what factors impact biodegradability and rate of biodegradation?

The term “biodegradability” refers to the ease with which an organic substance enters the natural carbon cycle where it is ultimately converted into microbial biomass and carbon dioxide or biogas, a mixture of carbon dioxide and methane (Angelidaki and Sanders 2004). Key factors influencing the rate and extent of biodegradation are the nature of the organic substance and their state - whether dissolved or suspended as particles. Additional environmental factors include the presence or absence of oxygen, salinity, temperature, pH, nutrients or other chemical co-factors. Less than optimal biodegradation conditions may occur in the field in, for example, cold, anoxic sediments. As biodegradability cannot be assessed for every conceivable environment, tests of biodegradability are needed for those environments where the organic substances of concern are likely to be discharged and can potentially persist and accumulate. For microplastics, such environments would include aerobic wastewater treatment, anaerobic digestion, seawater surface layers, the benthic marine environment, and the guts of aquatic animals.

For aerobic wastewater treatment and anaerobic digestion, three standard assays are available and could be adapted and standardized for quantitative assessment of microbead biodegradability. These three assays are the chemical oxygen demand (COD) test, the biochemical oxygen demand (BOD) test, and the biochemical methane potential (BMP) test. The COD test is the concentration of oxygen required for complete oxidation of the organic matter within a sample to carbon dioxide (Rice and Bridgewater 2012). Since the measurement of oxygen demand with molecular oxygen is difficult, COD is commonly measured with a substitute for O₂ - hot dichromate. The concentration of dichromate consumed is converted into a COD value using the oxygen equivalent ratio of O₂ to dichromate. Alternatively, COD can be computed from knowledge of the concentration of the organic substance, assuming its complete oxidation with O₂ to CO₂ and water. Anaerobic (methanogenic) biodegradability can be assessed by converting COD measurement into theoretical methane values that are compared to BMP.

The BOD test, per *Standard Methods* (2005) measures the concentration of dissolved oxygen used by aerobic microorganisms during aerobic biodegradation of an organic or nitrogenous substance. An inoculum (“seed”) of acclimated microorganisms or from a WWTP is incubated with a solution containing the organic substance of interest and oxygen uptake is monitored. As aerobic microorganisms grow, the concentration of oxygen removed from the solution increases over time, but eventually levels off at a plateau value - the ultimate BOD or ultimate biochemical oxygen

demand (BODL). This value represents the ultimate concentration of oxygen required for complete biodegradation of the organic substance. Changes in BOD over time can typically be represented with a first order model to determine the rate of oxygen utilization and the BODL. The difference between the COD and the BODL represents persistent or recalcitrant organic matter. The biodegradable fraction is the BODL divided by the COD.

The BMP test is commonly used to determine how much methane can be obtained from an organic substance under anaerobic (methanogenic) conditions (Owen et al. 1979; De Vrieza et al. 2015). This assay can potentially be adapted and standardized for measurement of methane production from a known concentration of microbeads during anaerobic degradation. In this case, the biodegradable fraction is defined as the BMP divided by the Theoretical Methane Production – the maximum possible methane production. The theoretical methane production of a unit mass of an organic substance can be determined from its known empirical formula or from its measured COD and the stoichiometric relationship $\text{CH}_4 + 2\text{O}_2 = \text{CO}_2 + 2\text{H}_2\text{O}$.

In both aerobic and anaerobic environments, the rate of degradation will depend upon the nature of the organic substance, especially whether it is in dissolved or particulate form. Solid particulates, such as microbeads, must undergo hydrolysis prior to microbial conversion into biomass and carbon dioxide or biogas. Rates of hydrolysis are limited by particle size and surface chemistry, such as the degree of hydrophobicity or hydrophilicity. Aquatic samples containing microbeads at equal concentrations as determined by a COD test could differ significantly in rates of degradation due to differences in particle size. Therefore, for microbeads of unknown or novel composition, a method is needed to normalize for size. This could potentially be accomplished by comparing the biodegradability of particles made from unknown or novel materials to that of particles having the same size but fabricated from a fully biodegradable reference material. Such a test could enable manufacturers to assess the effects of additives and manufacturing conditions and to design new products for biodegradability, not only for microbeads, but for other potential applications as well. Standardized assays could enable materials certification for environments of concern.

Cellulose is a suitable reference material for filamentous materials, and is already widely used as a control in biodegradability studies (Angelidaki et al. 2009; Wang et al. 2014). A potential reference substance for moldable materials is poly (3-hydroxybutyrate) (PHB), a natural and biodegradable biopolymer with no known negative impacts on ecosystem health. In nature, intracellular granules of PHB are naturally produced by many microorganisms. These microorganisms are at the base of the food chain for many animals. In fact, current evidence indicates that microbial biodegradation of PHB within the gut of aquatic animals (shrimp, prawns, fish, and crabs) is actually beneficial to the animal host. Penaeid shrimp fed *Bacillus* containing PHB exhibited better growth performance, survival, and resistance to pathogenic infections and ammonia stress (Laranja et al. 2014). Similar results were obtained for Chinese mitten crabs fed PHB-enriched live food (Sui et al. 2012).

When PHB granules are extracted from PHB-accumulating microorganisms and purified, they are fully biodegradable plastic-like materials that can be molded into different shapes and sizes. Addition of purified PHB particles to the diet of fish and prawns has been shown to stimulate PHB-degrading microflora within the gut (Liu et al. 2010) and prevent growth of pathogens, including pathogenic *Vibrio* (Defoirdt et al. 2006; Liu et al. 2010; Kiran et al. 2014), *E. coli*, and *Salmonella* (Boon et al. 2009). In a study of Siberian sturgeon, replacement of just 2% of the fingerling diet with PHB resulted in improved weight gain, increased specific growth rate, and increased survival compared to controls (Najdegerami et al. 2011). The intestinal microflora became more rich and diverse. In tests with European sea bass, PHB diet supplements of 2% and 5% of the feed increased the 6-week weight gain by 11% and 23%, respectively (De Scryver et al. 2010). Again, richness of the gut microflora increased. Other studies have evaluated the mechanisms by which PHB benefits aquatic organisms.

Feeding of small particles of PHB (25 to 30 μm) to brine shrimp (*Artemia fransiscana*) enhanced survival when the shrimp were exposed to pathogenic *Vibrio cambelli*, through the stimulation of the *Artemia* innate immune system. It is also interesting to note that the bacteria responsible for biological phosphorus removal in WWTPs, known as polyphosphorus accumulating organisms, produce large quantities of intracellular PHB granules under anaerobic conditions as part of the normal metabolic pathway (Tchobanoglous et al. 2014).

Microbeads made from PHB over a range of particle sizes could thus potentially serve as a “gold standard” for biodegradability in both the BOD test and a BMP test. Microbeads generated from novel materials should ideally exhibit biodegradability rates and extents comparable to that of PHB in aquatic (marine and freshwater) habitats and in gut microflora of aquatic fauna. Assays based upon particle biodegradability in seawater could thus be developed, enhancing current protocols (California State University and Chico Research Foundation 2007). Survival assays of critical indicator organisms could also be developed to protect the integrity of critical aquatic food chains.

Biofouling, an important first step in polymer biodegradation, may increase the density of microbeads, resulting in their transport into sediments. For example, if microbeads enter cold or anaerobic environments (e.g., sediments) then biodegradation may be slow. Besides biodegradation, microbeads may be subject to physical breakdown due to photolysis. Rate will depend on type of polymer, wavelengths of light and intensity (Yousif and Haddad 2013). Low density polymers (i.e., those that float) or those stranded on beaches may be especially vulnerable to photodegradation. This may also prime the polymer for more rapid biodegradation.

If we accept some types of plastic microbeads to be added to personal care products due to their biodegradability, then biodegradability should be relevant to aquatic habitats. Thus, the material should be 100% biodegradable in aquatic (marine and freshwater) habitats over a short time scale. In the best-case scenario, biodegradable would mean that it would degrade during the wastewater treatment process. In this case, the end of the life cycle for some microbeads will no longer be to be discarded in the environment (Baltic Marine Environment Protection Commission Helcom 2014; Martin and Eizhvertina 2014; Magnussen and Wahlberg 2014; New York State Office of the Attorney General 2015), the way some types of microbeads are today (e.g., polyethylene, polypropylene, polystyrene).

Is there a concern that contaminants from the water can adhere to synthetic plastic microbeads?

There is no doubt that hydrophobic organic contaminants and metals adhere to synthetic plastic microbeads (Napper et al. 2015). Microbeads are made of the same materials as other microplastics and passive samplers that are known to accumulate such chemicals. These materials have a high affinity for hydrophobic organic contaminants (Ogata et al. 2009; Teuten et al. 2009; Rochman et al. 2013a) and metals (Ashton et al. 2010; Rochman et al. 2014a). Polyethylene is the most common polymer in personal care product-associated microbeads and is one of the most sorbent polymers for hydrophobic organic pollutants. When microplastic, including a microbead, enters the aquatic environment it will accumulate chemicals and become associated with a cocktail of chemicals that include its own inherent chemical ingredients and a mixture of chemicals from ambient water. Under certain exposure scenarios, such chemicals may be bioavailable to wildlife and may cause harm (Rochman et al. 2015b).

The nature of both the polymer and contaminant control the extent of sorption. It is likely that more polar, more biodegradable polymers will exhibit lower sorption potential for hydrophobic contaminants. In addition, biofouling of the polymer surface may alter sorption of contaminants by

increasing the surface polarity. Ionizable contaminants (e.g., some metals) may show greater sorptive potential to such surfaces. Hence, further research on this subject is recommended.

In addition to chemical contaminants, plastics may serve as substrates for organisms, including pathogens. It has long been known that marine organisms adhering to floating debris may be transported long distances. This was graphically illustrated following the 2011 Japanese tsunami, when associated debris reached the western U.S. coastline. In addition to transport of exotic organisms, biological communities growing on plastic debris may differ from those that form on natural substrates. Zettler et al (2013) observed that opportunistic marine pathogens of the genus *Vibrio* dominated the community on some plastic samples. Likewise, McCormick et al (2014) observed that bacterial assemblages colonizing microplastic in an urbanized U.S. river were less diverse than and taxonomically different from those in the water column and suspended organic matter. The taxa identified included plastic decomposing organisms and pathogens. These observations suggest that potential risks from biological opportunism and adaptation associated with plastics must also be considered.

What is the potential geographic range of impact, i.e., is their impact quite local (like sediment) or does their buoyancy allow them to travel great distances (more like air)?

The properties of different types of polymers will guide their fate in aquatic environments. Microbeads have been detected in the environment in both surface waters (Eriksen et al. 2013) and sediments (Castañeda et al. 2014). A microbead, and microplastic in general, that has a positive buoyancy will float and its fate will be determined by the currents (Maximenko et al. 2012). As such, they have the potential to travel long distances, which is likely why they have been found distributed about the Laurentian Great Lakes (Eriksen et al. 2013). High concentrations of microplastics are found in locations great distances from the source (e.g., the subtropical gyres or “garbage patches” and beaches of remote islands such as Midway Island in the Pacific). Because microbeads often look no different than any other fragment of microplastic, it is difficult to determine if the source of any of the microplastic found in the subtropical gyres is from personal care products.

Due to the type of polymers commonly used, most microbeads are initially buoyant. This facilitates their mobility and potential dispersion in water bodies. Still, many may sink when they are made from denser polymers or become biofouled. Thus, aquatic sediments may be a substantial, yet underappreciated sink for microplastics, including microbeads (Claessens et al. 2011) which have been reported at the bottom of the St. Lawrence river (Castañeda et al. 2014).

The source of microbeads and other microplastic may help determine their fate. During wastewater treatment, many microbeads may end up in clarifier solids or scum. In the U.S., these solids are generally incinerated, landfilled, or land-applied. Non-biodegradable microbeads remaining in land-applied biosolids can enter agricultural environments and natural waterways through runoff. Greater microplastic abundances have been observed near developed areas (Yonkos et al. 2014). However, physical processes (e.g., currents) may concentrate plastics elsewhere to remote open oceans, beaches, and estuaries.

Potential Impact

At this time, there is very little information regarding impacts from microbeads on aquatic organisms. However, the body of scientific evidence regarding impacts from microplastic in general is growing and can inform how different types of microplastic debris affect wildlife.

Are there physical impacts of microplastic to aquatic organisms?

The science relevant to the impacts of microplastic debris in the marine environment is still in its infancy. The majority of evidence regarding impacts come from laboratory studies and generally involve invertebrates and fish. Many of these experiments expose test organisms to very large concentrations of microplastic which are not environmentally relevant. Nonetheless, however, these studies help us understand the ways in which microplastics may impact wildlife upon exposure. Experimental evidence has demonstrated that microplastic can be toxic to aquatic animals at the embryonic stage, affecting development (Nobre et al. 2015). For zooplankton, microplastic can adhere to appendages, alter their feeding behavior and when ingested can cause decreased fecundity and mortality (Cole et al. 2015). In benthic worms, exposure to microplastic can cause reduced feeding, weight loss and oxidative stress (Besseling et al. 2012; Browne et al. 2013). In mussels, smaller microplastics have been shown to cross cell membranes (Browne et al. 2008) and cause inflammation (Von Moos et al. 2012). In fish, ingestion of microplastic has been shown to alter behavior (De Sá et al. 2015) and cause liver toxicity and changes in gene expression (Rochman et al. 2013b; 2014b).

Compared to evidence from laboratories, the weight of the evidence for physical impacts of microplastic in nature is incredibly small. One study demonstrates the increasing population of *Halobates sericeus*, a marine insect, linked to the increasing concentrations of microplastic in the North Pacific Subtropical Gyre (Goldstein et al. 2012). Future research is thus imperative to truly understand impacts to wildlife.

Is there a risk that synthetic plastic microbeads that have adsorbed contaminants could serve as a vector to aquatic organisms?

One potential risk to wildlife in regard to microplastic, including microbeads, is that they can be a source of contaminants to wildlife. This could occur via multiple pathways.

- 1) Microbeads and other microplastics may leach chemical contaminants into the environment, thus exposing wildlife through water, particulate matter, or food chain pathways. This scenario is of concern with chemical ingredients of the plastic or chemical additives (those added during production) due to high concentrations, which are often at the percent level. Evidence that microplastic is a source of chemicals that are inherent to the plastic itself has been demonstrated in seabirds (Hardesty et al. 2015; Tanaka et al. 2013) and fish (Rochman et al. 2014c).
- 2) Chemicals that accumulate on microplastic and/or microbeads may transfer to an animal upon ingestion. There are decades of published literature that indicate that particles, such as sediments, can sorb pollutants from the water and then transfer these to biota that ingest them. There is evidence that microplastic has been ingested by hundreds of species in nature (Gall and Thompson 2015). Microbeads specifically, have been detected in fish (Mason, S. *unpublished work*). Under certain exposure scenarios, chemicals from the plastic will transfer to an animal upon ingestion (e.g., if the chemicals on the plastic are greater than already present in the animal) and has been demonstrated in the laboratory in lugworms (Browne et al. 2013), mussels (Avio et al. 2015), amphipods (Chua et al. 2014) and fish (Rochman et al. 2013b). Correlations between plastic ingestion and bioaccumulation of sorbed chemicals (metals and polychlorinated biphenyls; PCBs) in the wild have been demonstrated in seabirds (Ryan et al. 1988; Lavers et al. 2014).

What is the evidence of bioaccumulation and is it worse in certain types of species such as mollusks, filter feeding forage fish, etc.?

For microbeads specifically, there is little evidence of ingestion by organisms in the wild. This is likely because it is difficult to tell the difference between a microbead and microplastic fragments or beads from other sources. However, Setälä et al. (2014) observed ingestion of fluorescent polystyrene microspheres by a number of species in the laboratory. Microbead-like microplastic (i.e., microplastic of similar type, size, and shape as microbeads) has been documented in many species of wildlife across multiple trophic levels and habitat-types (Gall and Thompson 2015). In terms of bioaccumulation, this can occur in two ways. There is evidence that, if small enough, the microplastic itself can bioaccumulate in the tissues of an organism (Browne et al. 2008). Due to degradative processes, microbeads and other microplastics will likely fracture into ever smaller particles over time, making them available to an increasing percentage of aquatic life. Moreover, as discussed above, there is evidence that the chemicals from plastics can bioaccumulate in an animal upon exposure to plastic via the water column or ingestion (Browne et al. 2013; Rochman et al. 2013b, 2014b; Chua et al. 2014; Tanaka et al. 2013).

When researchers have attempted to observe trends of microplastic ingestion across trophic levels or species, a trend is generally not found. For example, three studies found no statistically significant difference between ingestion of plastic in pelagic fish versus benthic fish (Lusher et al. 2013; Neves et al. 2015; Rochman et al. 2015c). Filter-feeders will, by virtue of their feeding strategy, likely ingest greater amounts of suspended microplastic and/or microbeads (Van Cauwenberghe and Janssen 2014). Several species of mussels and oysters sampled from the wild have been found to have microplastic contamination (Van Cauwenberghe and Janssen 2014; Li et al. 2015; Rochman et al. 2015c).

Is there a risk that synthetic plastic microbeads that have adsorbed contaminants could serve as a significant health risk for humans?

We do not currently have enough scientific evidence to answer the significance of any risk to humans because we do not know yet the mechanisms by which microplastic could cause harm in humans or the levels at which harm could occur. The potential risk from marine microplastics via consumption of contaminated seafood was the subject of a 2014 U.S. EPA/NRC-sponsored forum (Summary of Expert Discussion Forum on Possible Human Health Risks from Microplastics in the Marine Environment, EPA 2015).

Aquatic sediments and organisms living downstream of polymer product manufacturers and wastewater treatment plants may be contaminated with chemical additives (Hale et al. 2008). These contaminated organisms may then act as significant source to humans and wildlife (Hale et al. 2001). The contribution directly from microplastics is yet uncertain.

We do know that microplastic is ingested by species that we consume as seafood, including both bivalves (e.g., oysters and mussels) and fish (Van Cauwenberghe and Janssen 2014; Rochman et al. 2015c; Li et al. 2015; Neves et al. 2015). Microplastic has also been detected in sea salt (Yang et al. 2015). Upon ingestion of sea salt or whole bodies of organisms such as oysters, mussels or even small fish, we are exposed to both the microplastic itself and the chemical mixture. As such, potential harms could be chemically or physically related. Given the current literature, the benefits of eating seafood likely outweigh any harms due to microplastics.

Stepping back and considering the indoor environment, substantial burdens of several polymer additives have been detected in humans, and the likely exposure route is through ingestion and

inhalation of contaminated dust in homes, offices, and vehicles (Wu et al. 2007). Microplastics within this indoor dust is likely to also play a role in affecting human health.

Are there any research findings on microplastics specific to the Chesapeake Bay and its tributaries?

In 2014, Lance Yonkos and colleagues published a study about the presence and quantity of microplastic debris in the Chesapeake Bay. They reported the presence of microplastic in four estuarine rivers in the Bay – the Patapsco, Rhode, Corsica and Magothy Rivers (Yonkos et al. 2014). Microplastic was present in 59 of 60 samples with concentrations ranging from <1 to >560 g/km². The study found the greatest concentrations in Patapsco River and the smallest in Rhode and Corsica Rivers. Microplastic concentrations were correlated with population densities and extent of urban/suburban development within the watersheds. Highest levels appeared after rain events and these likely evaded collection or removal by normal wastewater treatment processes.

In September of 2015, Julie Lawson of Trash Free Maryland and Chelsea Rochman sampled for microplastic debris in the Chesapeake Bay from the Back River to the mouth of the Potomac. Data are still being analyzed, but microplastics were visually observed in many of the 60 samples taken. Figure 1 is a picture of a sample taken in the Back River with several blue pieces that are undoubtedly microplastic. In addition to samples from within the Bay and its tributaries, Rochman sampled final effluent from three WWTPs in the Maryland region. Again, data have yet to be analyzed by Fourier transfer infrared spectroscopy (FTIR), but microplastic were visually observed in samples.



Figure 1. Image of the contents of a sample taken by a manta net with a 333 μm mesh deployed in the Back River for 15 minutes at 2 knots in September of 2015 (Julie Lawson of Trash Free Maryland).

Is there a federal toxicity level for plastic microbeads?

The review panel is not aware of a federal toxicity level for plastic microbeads. At the moment, one has not been designated and one will likely not be developed. This is likely because they will be banned from personal care products nation-wide. That said, there will likely be a standard toxicity

test developed for microplastic which will include thresholds for toxicity in the same way as other chemicals. This will not be an easy task, because like many groups of contaminants, there are many different types of microplastic and they are often associated with many other chemicals *in situ*.

Treatment of Microbeads/Microplastics

What is the expected removal of microbeads/microplastics in conventional wastewater treatment facilities in the Chesapeake Bay watershed? What are the removal mechanisms? What is the fate of the microbeads/microplastics?

Removal of particles in wastewater depends on particle size, biodegradability, and hydrophobicity. Most conventional WWTPs include primary clarifiers as an initial process that allows particles to settle by gravity or float to the surface (scum) for removal. A large proportion of polyethylene or polypropylene microbeads would be expected to settle or float in the primary clarifier, either as a result of the transfer of larger microbeads to the bottom of the clarifier by gravity or to the scum layer by floatation, resulting in effective removal from the liquid stream. Smaller microbeads would be expected to attach to/coagulate with/enmesh with other sewage solids based on the hydrophobic nature of the microbeads, with “ballasted” sedimentation or floatation of the microbeads in the primary clarifier. Primary clarifiers would therefore be expected to remove a large portion, but certainly not complete, of microbeads in the size range of 20-500 μm , with proportionally greater removal of larger particles. Settled primary solids are managed in downstream solids handling processes, discussed below, and microbeads would be transferred to those processes in an unmodified form. Primary clarifier scum is also occasionally directed to solids handling processes, but in most conventional WWTPs, this stream is concentrated and directly landfilled (greasy, rancid, putrescible material). Small WWTPs often do not include primary clarifiers, but those that do maintain a positive barrier for partial removal of microbeads. Additionally, since larger microbeads would be expected to float to the scum layer in a primary clarifier, and since most primary scum is concentrated and landfilled, the fate of this fraction of microbeads should be excluded from release to the environment.

Some innovative WWTPs are now installing micro-screening processes in place of primary clarifiers, with excellent particle removal to <100 μm . This would be an even better barrier for microbeads, but these technologies have been installed in only a handful of treatment plants.

The vast majority of all conventional WWTPs include some form of biological treatment as the next step in the liquid treatment train. For nearly all of the WWTPs in the U.S., this is now some form of the activated sludge process. Dutch WWTP data suggest about 90% removal of microbeads in activated sludge plants (Magnussen and Wahlberg 2014). This is to be expected, as microbeads should be well enmeshed in biological flocs, based on their size and hydrophobic characteristics, even if not biodegraded in the activated sludge process itself. In the size range of 20-500 μm , polyethylene or polypropylene microbeads would not be expected to biodegrade within the solids residence time (typically 2-30 days) of biological flocs in the activated sludge process, and therefore the removed microbeads would be transferred mostly unmodified with the primary solids to the solids handling processes. While the activated sludge process would provide significant removal of microbeads, again, one should not expect complete removal particularly down to sizes approaching 20 μm , and given the non-ideal nature of particle and floc separation in standard secondary clarifiers.

The majority of WWTPs in the Chesapeake Bay watershed employ tertiary filtration processes, the purpose of which is either to polish remaining suspended solids for compliance with phosphorus treatment objectives or to meet low suspended solids and pathogen indicator requirements for reuse applications. These filtration processes are commonly either granular media filters (mono-media,

multi-media, or deep bed) or cloth media filters. A typical expectation of these tertiary filters is 90% removal of 10 μm particles, declining to roughly 10% removal of particles approaching 1 μm (Tchobanoglous et al. 2014). Thus, if a plant contains conventional tertiary filtration, excellent microbead removal would be expected. Again, complete or 100% removal should never be expected, particularly approaching the smaller 20 μm microbeads. The fate of microbeads in tertiary filtration processes is the return of water used to backwash the filters to the head of the WWTP, resulting in microbeads being redirected effectively unmodified to the primary solids, scum, or the waste biological solids from the activated sludge process.

Primary and waste activated solids containing effectively unmodified microbeads are managed differently depending on the specific facility. Those processes include thickening/dewatering and some sort of stabilization, typically incineration, anaerobic digestion, or aerobic digestion. For WWTPs with incineration and typical air pollution controls, there would seem to be little concern of microbead return to the terrestrial or aquatic environment. For WWTPs with digestion, the fate of those stabilized solids is either landfilling or land application. For polyethylene or polypropylene microbeads, which are likely unchanged through conventional digestion processes, could result in the transfer of microbeads to agricultural land and perhaps to the aquatic environment through surface runoff. As >50% of the domestic wastewater in the U.S. is treated at WWTPs employing anaerobic digestion for solids handling (Tarallo and Kohl 2014), the development of microbeads that would be biodegraded within the residence time of these processes (typically 15-50 days) would be a reasonable consideration. Emerging digestion pretreatment processes, such as thermal hydrolysis, could improve both the rate and extent of microbead biodegradation in conventional anaerobic digesters.

What is the extent of microbead/microplastic discharge from combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs)?

Discharge of untreated sewage from CSOs and SSOs during wet weather events would result in direct transfer of microbeads to the environment. However, most of the larger CSO and SSO cities (>1M people) in the U.S. have been under EPA enforcement action to significantly minimize or eliminate overflows in the last 20-30 years. Considerable work has already been completed or is in construction/planning to minimize overflows. As an example, Hampton Roads Sanitation District (HRSO), which under enforcement action for SSO abatement, is currently embarking on a ~\$2B spending program to minimize SSOs, when the current annual average amount of raw sewage spilled through wet weather SSO overflow events is approximately 0.03-0.05% of the total volume of sewage fully treated on an annual basis. The discharge of raw sewage from CSOs and SSOs has become a much less significant concern in recent years, and it will continue to decline.

Are there emerging technologies that could enhance removal of microbeads/microplastics? What is the potential for the implementation of these emerging technologies?

A very few advanced WWTPs which are focused on providing reuse water for potable applications also include membrane microfiltration and ultrafiltration processes. These processes would be expected to provide very close to 100% removal of particles down to <1 μm . These upgrades are extremely costly, combined with other processes and systems needed to achieve potable reuse. An estimated cost of converting a representative 20 million gallons per day (MGD) conventional WWTP to that capable of producing water for potable reuse is \$130M to \$170M with an increase in capital of \$3.5 to \$7.0M/year. This level of cost would seem unreasonable to ensure the complete removal of small microbeads. Additionally, these removed microbeads would continue to be diverted to solids handling processes with the same fate as noted above.

What would be the expected removal of microbeads/microplastics in conventional drinking water treatment plants using surface water supplies? Is additional treatment warranted?

For drinking water treatment plants using surface water supplies, there is a very strong emphasis placed on the removal of turbidity through the use of processes including coagulation/flocculation, sedimentation, and granular media and membrane filtration. The reason for this is to provide for physical removal of pathogens such as bacteria, *Giardia* (and cysts), *Cryptosporidium* (and oocysts), and viruses. EPA regulations require 95% compliance with a filtered effluent turbidity of 0.3 nephelometric turbidity unit (NTU), and most facilities operate with a typical maximum turbidity objective of 0.1 NTU. This corresponds to high log removal of particles in the 20-500 μm size range, up to 90% removal of particles $<10 \mu\text{m}$, and good removal of particles $<1 \mu\text{m}$ (Crittenden et al. 2005). Physical removal of pathogens is combined with chemical disinfection approaches for a “multiple barrier” approach. Drinking water facilities that are required to perform membrane filtration instead of, or in addition to, granular media filtration exhibit nearly complete, though not perfect, removal of particles $<1 \mu\text{m}$. There is minimal concern for the presence of microbeads in the public water supply. Still, a test to confirm this might be beneficial, as microplastic has been found in beer in Germany (Liebezeit and Liebezeit 2014), the source of which may have been drinking water.

What are the constraints or costs associated with removing microplastics from the waste stream if such is required in lieu of a prohibition on their use in personal care products? Does it make sense to place most of the burden of microbead/microplastic control on WWTPs?

As noted above, conventional WWTPs will never achieve 100% removal of microbeads, though facilities employing tertiary filtration probably are much more efficient at removing microbeads from final effluent. It is unclear which if any of WWTPs sampled in Table 1 below employ tertiary filtration, but studies that have looked for microbeads find them both in conventional WWTP effluents and in the effluent from plants that employ tertiary filtration, albeit substantially less frequently in the latter (New York State of Office of the Attorney General 2015). Moreover, unless a facility also uses incineration for solids handling, non-biodegradable microbeads would be expected to be present in the biosolids being produced at a conventional WWTP. This may have implications for the beneficial reuse of biosolids products in agricultural applications. For this reason, it does not make sense to place most of the burden of microbead control on WWTPs.

The state of Minnesota recently banned the sale of products containing triclosan, a soluble and hydrophilic antibacterial pollutant. Is this an appropriate model for regulation? In the case of microbeads/microplastics, significant removal (though not 100%) is expected in conventional WWTPs. Does it make sense to also consider dissolved products like triclosan, which probably represent a much greater risk and threat?

Most microbeads in personal care products likely carry few if any additives. Hydrophilic additives, such as Triclosan, likely exhibit minimal sorption to hydrophobic microbeads from the personal care products themselves. Hence this model likely does not pertain to the vast majority of products containing microbeads.

Can non-degradable plastic microbeads be used to remove PCBs from groundwater?

Polymeric resins have previously been demonstrated to remove hydrophobic compounds, such as PCBs, from contaminated water. The PCBs are retained on the resin and the purified water passes through. When the resin is fully loaded, the PCBs may be stripped from the resin with solvents. However, Velzeboer et al (2014) recently reported that other materials, such as manufactured carbon

micro-tubes, may be more efficient than plastics at removing PCBs from water. Hence, the use of non-degradable plastic microbeads is likely not the most effective approach.

Potential Urgency

Is there any evidence of the direction of potential impact, i.e., is it being seen in increasing quantities at local or regional scales?

As a whole, microplastic debris is being observed in increasing quantities (Goldstein et al. 2012) and regions of the oceans. Microplastic has now been detected in a variety of habitat-types: on the surface (Van Sebille et al. 2015) and at the bottom of the ocean (Woodall et al. 2015), in rivers (Castaneda et al. 2014) and lakes (Eriksen et al. 2013) and even in Arctic sea ice (Obbard et al. 2014). Some of this may be due to sampling bias; i.e., people are beginning to sample for microplastic more often and in more regions and habitat-types than before. In addition, as the technology and methods advance, scientists are able to detect smaller and smaller pieces of the plastic debris. Improved sampling and analytical methods are sorely needed at a large-scale to establish the true burdens of microplastics in the environment. This should be a research priority. In the Great Lakes, microbeads were recently reported to constitute 58% of the total microplastic burden in the water column (Eriksen et al. 2013). This was likely due to their proximity to urbanized areas and the enclosed nature of the basins. Overall, microplastic burdens in the Great Lakes were similar to what was reported in the Pacific and Atlantic Ocean gyres (“garbage patches”).

Is this really a problem that rises to the level of taking individual state action? That is, is this having an impact (or is this likely to have an impact) on the Chesapeake Bay and its tributaries?

The science of measuring the ecological impact of microplastic on wildlife is still in its infancy. We know very little about the ecological effects of this material (Rochman et al. 2015d). Still, there is evidence that microplastic debris can harm an individual organism at ecologically relevant concentrations (Rochman et al. 2013b; 2014b). We also know that microplastic debris is detected in seafood for human consumption. It is important to note that any information relevant to microplastic debris in general is relevant to microplastic debris and thus microbeads in the Chesapeake Bay, especially since there is evidence of microplastic contamination in this region.

Removing microplastic from personal care products is a simple solution to a large-scale and global problem. The microplastics issue does not respect state borders and involves interstate commerce. Waste management is generally managed locally, although there are obviously global implications. As such, taking action locally is truly beneficial. Due to the fact that there are many more sources of microplastic than microbeads, a number of mitigation strategies are required to prevent microplastic contamination.

As an exercise, and in attempts to put a value on the contamination from microbeads as a source, we can estimate the amount of contamination from microbeads coming off of the U.S. every day. Although data demonstrating the quantities of microbeads in final effluent from WWTPs are piecemeal, it provides a starting place to estimate how many microbeads may be entering aquatic habitats. Studies report a range of 0 – 7 microbeads L⁻¹ of water in the final effluent from WWTPs (Table 1), which is often discharged directly to aquatic habitats. Less than seven microbeads per L of effluent may not sound significant; however, WWTPs in the United States are capable of treating >160 billion L of water everyday (U.S. Census 2010). Using a conservative estimate, assuming all WWTPs operate at half capacity (i.e., treating 80 billion L/day) and that 0.1 microbeads are found per

L of effluent (the average of the two studies which found a smaller amount of microbeads; Magnusson and Wahlberg 2014; Martin and Eizhvertina 2014), we calculate that 8 billion microbeads per day may be emitted into aquatic habitats in the U.S. alone (Rochman et al. 2015a). If you line these microbeads up end-to-end, assuming they are 100 μm spheres, you can wrap these beads around the Earth more than 7 times! As such, any mitigation that removes this source of microplastic from local watersheds, removes a measurable source of microplastic debris.

In Table 1, the number of WWTPs where samples were collected and the total number of samples collected, the smallest mesh size used for filtration, the average number of microbeads per volume of water found in the final effluent with the standard deviation and the % retained in the sludge are displayed for each individual study.

Table 1. Available studies which have quantified microbeads in final effluent from WWTPs.

Study	# Plants analyzed (total # of samples taken)	Filtration mesh size	Average # microbeads in final effluent (\pm S.D.)	% Retained in sludge
Magnusson & Noren, 2014	1 (4 samples of 50m ³)	300 μm	3.75 m ⁻³ (\pm 1.25)	99%
New York State Office of the Attorney General, 2015	35 (?)	355 μm	Quantity not reported. Reported presence from 25 plants.	not measured
Baltic Marine Environment Protection Commission HELCOM, 2014	1 (1 sample of 8L)	20 μm	7 L ⁻¹	95%
Martin & Eizhvertina, 2014	2 (12 samples of 1L)	1.2 μm	0.25 L ⁻¹ (\pm 0.6)	not measured

General Recommendations

Legislation has been passed in many states and now federally. In addition, industry representatives have agreed to remove microbeads from several of their products. Still, much work remains to be done to ensure that *persistent* microplastic particles are not released into the ocean. In several debates, the argument is raised that there is not yet enough scientific evidence about microplastic to support legislation. The review panel disagrees that current gaps in our understanding should delay active solutions. While the panel recognizes that questions remain regarding the persistence, fate, and hazards of some types of microplastic sources specifically, much of this can be understood by reviewing the literature about microplastic debris more generally. Microplastic is persistent, impractical to clean up once it enters the waste stream, and has negative impacts to organisms. The probability of risk is high relative to the simplicity of the solution and the clarity of the benefits. Removing microplastic from products and replacing them with safer alternatives is a simple solution to a global problem—stopping persistent microplastics at the source and ultimately protecting water quality, wildlife, and resources used by people, including seafood and safe drinking water.

Legislation should be based on a complete understanding of the range of microbead applications. For example, small acrylic, melamine, and urea-based abrasive beads are used in sandblasting. The recent Microbead Free Waters Act applies to “non-prescription rinse-off cosmetics, including toothpaste.” The wording is important. If legislation applies to only a subset of microbead applications, it likely it

will not result in “microbead-free” waters. As such, we recommend that this legislation is viewed as just the beginning of a suite of management strategies for microplastic.

Legislative Definitions

From a technical perspective, what are the deficiencies of existing legislation?

Public support for banning microbeads from products is growing rapidly and has prompted action from companies that manufacture products containing microbeads, and from legislative bodies. For example, in the United Kingdom, >25 companies vowed to remove microbeads from all their products. Several multinational companies, including Unilever, The Body Shop, IKEA, Target Corporation, L’Oreal, Colgate/Palmolive, Lush, Procter and Gamble, and Johnson & Johnson have pledged to stop the use or sale of microbeads in their “rinse-off” personal care products (i.e., those designed to be rinsed down the drain). Agreements should go into effect within the next three years. In parallel, >70 non-governmental organizations (NGOs) from more than 30 countries have been working on a top-down solution: legislative action to ban microbeads from personal care products has been written and proposed in Canada, Australia, and several countries in the European Union. In the United States, several states, led by Illinois and including California, Colorado, Connecticut, New Jersey, Maine, Maryland, and Wisconsin have successfully passed legislation banning the sale of personal care products containing microbeads in the next 3-5 years. In the U.S., new legislation has also been passed federally.

While laudable, the focus on “rinse-off personal care products” does not remove all sources of microbeads from the aquatic environment. Such agreement excludes cosmetics and other personal care products such as deodorants, lotions, and other products that we do not immediately, but do ultimately, rinse off. There are also applications (e.g., industrial and household cleaners) for microbeads added to products that are not considered “personal care”. This is not reason to stop any legislation, but it is useful to keep in mind for future legislation or regulation. Moreover, there are what many have considered to be loopholes in the legislative bills and agreements proposed and/or passed. One issue lies with how the terms “plastic” and “biodegradable” were defined in some of the state bills. For example, the legislation passed in Illinois defined plastic as synthetic materials that “retain their defined shapes during life cycle and after disposal.” This wording does not include plastic microbeads that may biodegrade only slightly, thus changing their defined shape in an unspecified time period. Many of the microbeads currently on the market are allowed under this definition when they degrade slightly, but are not truly biodegradable in aquatic habitats. Finally, and what seems to cause the most confusion, is the term “biodegradable” itself. Several companies and legislation promise to remove “non-biodegradable” microbeads from personal care products. When the term biodegradable is not defined, or international standards for biodegradability are cited that do not mandate full degradation (especially full degradation in aquatic environments), it allows for materials to be used in products that degrade only slightly during a 1-year period of time (e.g., polylactic acid). A material defined as “biodegradable” under legislation in Illinois may degrade slightly, changing in shape and form, but can ultimately persist and remain bioavailable to wildlife. It is noteworthy, that the federal bill and California state bill were different, and banned any plastic microbead from “rinse-off” products. This wording has been scrutinized as being too restrictive by not allowing new plastics that are truly degradable and thus benign by design.

What is appropriate wording for a bill that balances the interests of the environment, consumers, and manufacturers, and ensures that both (a) non-biodegradable plastic microbeads are banned as desired, and (b) innovative alternatives are permitted if they are biodegradable in all relevant environmental systems within a meaningful time period?

It could be suggested that microbeads need to meet specific end of life criteria – and as long as they “pass” they would be allowable. Ideal criteria would include an internationally accepted biodegradation test, but that is unlikely to be successful. Therefore, one could propose that the material must pass a BOD and BMP test as previously described. This would give innovators and brand leaders the benefit of setting a clear criteria – if their material passes the test, they will be allowed.

What are some of the proposed replacements for conventional plastic microbeads that are currently available to manufacturers?

Some proposed replacements for conventional plastic microbeads include: polyhydroxyalkanoates (PHA), polylactic acid, cellulose acetate, walnut shells, apricot pits, avocado pits, silica, jojo beads, and pumice seeds.

Microbead-Free Waters Act of 2015

What is beneficial about the federal legislation banning microbeads?

The Microbead-Free Waters Act of 2015 (“The Act”) federal legislation has been beneficial because it has publicized the issue of persistent plastics in the environment and does remove one of the many sources of microplastic to aquatic habitats. It is an important first step and indicates broad consensus among legislators, industry, scientists and environmental advocates that microplastics in general, and microbeads in particular, may pose unacceptable risks to the environment.

What is the federal legislation missing?

A - What applications for microbeads are not included under the federal legislation?

The Act focuses narrowly on microbeads for rinse-off products, which includes microbeads and exfoliates. Hence the title of the Act is potentially misleading as it suggests that it will eliminate all introductions of microbeads to U.S. waters. The legislation does not cover microbeads in other personal care products such as make-ups, deodorants, lotions, or other household cleansers. Additionally, the legislation does not cover other microbeads that may enter the aquatic environment from their use as industrial abrasives, e.g., such as those from cleaning ship hulls, and in surface coatings such as paints.

B - Does the language in the bill allow for novel innovative scientific solutions now and in the future?

The wording of the Act does not allow for innovative scientific solutions that could be cost-effective, environmentally benign, and acceptable to consumers. The Act prohibits (at defined future timepoints) “the manufacture and introduction or delivery for introduction into interstate commerce of rinse-off cosmetics containing intentionally-added plastic microbeads”. Plastic microbeads are defined as “any solid plastic particle that is less than five millimeters in size and is intended to be used to exfoliate or cleanse the human body or any part thereof”. Accordingly, the legislation actually would prevent current and future innovative solutions that utilize plastics.

For example, use of the commercially available, naturally occurring biopolymer PHA, which biodegrades on land and in marine and freshwater environments, would arguably be prohibited because PHA (depending on the formulation) is thermoplastic. Companies around the world are trying to develop commercially viable plastics that are environmentally friendly, and while the market

for cosmetic microbeads is relatively small, the Act discourages innovation in the field of plastics. If a company was able to develop a novel plastic that has suitable cost/performance characteristics and also degrades (whether biodegradable or otherwise) to environmentally benign oligomers, monomers, or other small molecules, the Act would actually prevent its use in rinse-off cosmetics. This is particularly unfortunate when contrasted with the fact that in the meantime, the Act would permit the use of environmentally harmful plastic microbeads for personal care or other products/applications that are not rinse-off cosmetics, as described above.

C - How can the federal bill language be clarified or enhanced?

The Act itself has now been passed by both Houses of Congress and signed by the President. As described above, the Act is arguably (i) too restrictive when it comes to solutions (i.e., it prevents use of any plastic microbeads in some applications, even if they are environmentally benign), and (ii) too limited in the scope of products to which it applies (i.e., only applying to rinse-off cosmetics). Accordingly, any improvements to the language of the Act should address these two issues. As noted above, the actual title of the Act oversteps its likely impact on the prevention of the introduction of all microbeads to U.S. waters.

Unfortunately, addressing these deficiencies is not as easy as it may seem, and it is important that any “fixes” do not go too far in the other direction. In addition, our knowledge is at present poor in regard to all important uses of microbeads, their relative volumes, the likelihood of their entry into U.S. waters as a function of use, their removal by various wastewater treatment strategies, and their ultimate fate in U.S. waters.

Careful definitions are required. This is particularly important in trying to define plastics that might be permissible in personal care (and other) products. For example, it is tempting to allow for “biodegradable” plastics, but how would biodegradable be defined? What if a product is biodegradable in a compost heap, but not in a landfill, or not in water? What about the time frame of degradation? What about chemical degradation, or photodegradation? How would you define plastic, and is that definition even necessary? These concerns and questions are not limited to intentionally added microbeads in rinse-off cosmetics, but potentially extend to other products. Exceptions for environmentally friendly plastics should require verifiable compliance with one or more standard tests, and allow for evolving science and understanding of the environmental issues.

What are other sources of microplastics?

For microplastics in particular, sources are generally categorized as primary or secondary. A source of microplastic is considered primary when it enters the environment as microplastic (i.e., <5 mm or <1mm in size). Examples of this would be fibers from washing machines (Browne et al. 2011), microbeads from personal care products (Eriksen et al. 2013), or the spillage of pre-production pellets from industry (Harper and Fowler 1987). A secondary source results when a larger piece of plastic debris breaks into micro- or nano-sized pieces via chemical, biological, or physical degradation processes. Point-sources of microplastics relevant to Chesapeake Bay may be stormwater, WWTP effluent, land-based or maritime-based litter, and agricultural runoff.

What are suggestions moving forward?

A - Urgent research needs

Adequate and harmonized analytical techniques are needed to detect the presence, composition, and quantities of microplastics of many sizes in diverse environmental media (e.g., water, wastewater, sediments, sludge, and organisms).

At present, analytical methods are still evolving. Microbeads exist in a range of sizes that include the originally manufactured beads as well as fragments. It is likely that the smallest fragments, which presently are seldom reported due to analytical difficulties, are the most abundant. Due to their small size, they would also be the most bioavailable. Techniques are needed that are able to identify large numbers of discrete microplastics in complex environmental samples. The most promising approaches appear to be spatial imaging-based spectroscopic techniques capable of identifying polymeric composition (e.g., Raman or Fourier transform infrared microscopy).

The approach to collection of the samples themselves is also critical. Most studies to date have focused on surface waters and shorelines. Particle distributions may also be skewed by the manner of collection, e.g., using a too wide net mesh for water. In virtually all cases, some purification of the collected sample prior to spectroscopic analysis is needed to eliminate interferences from naturally occurring materials such as plant detritus. Due to these difficulties, much of the data now available focuses on the larger particles in the simplest matrices. Hence, the true extent of the problem is uncertain, but is likely greater than currently appreciated.

An urgent need is to identify the most effective and encompassing collection and analysis approaches and expanding their availability within the concerned community (including academia, government, and industry).

B - Monitoring recommendations

Monitoring should include entry points to aquatic systems, ambient levels in diverse environmental media including aquatic organisms, processes (both naturally occurring and anthropogenic) that affect the composition and fate of microbeads, and toxicological consequences.

C - Some recommended innovative solutions and technologies

1. Initiation of a long-term monitoring study to quantify microplastic in the Chesapeake Bay and better understand their sources and sinks.
2. Educational outreach programs for the public and industry.
3. Further legislation that prevents microplastic from entering aquatic habitats (e.g., implementing mandatory filters on washing machines to prevent fibers from textiles from entering waterways).
4. Instigating innovation of more sustainable products that are benign by design.
5. Better best management practices for waste management such as including trash-capture devices on storm drains, building water wheels at river mouths or implementing TMDLs in waterways for trash.

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