

Report of the NJDEP-Science Advisory Board

Human Health Impacts of Microplastics and Nanoplastics

Prepared by the Public Health Standing Committee

Approved by the
NJDEP Science Advisory Board

Dr. Judith Weis, Ph.D. (chair)
Clinton J. Andrews, Ph.D., P.E.
John E. Dyksen, M.S., P.E.
Raymond A. Ferrara, Ph.D.
John T. Gannon, Ph.D.
Robert J. Laumbach, M.D., MPH
Peter B. Lederman, Ph.D., P.E.
Robert J. Lippencott, Ph.D.
Nancy C. Rothman, Ph.D.
Tavit Najarian, Ph.D.
Michael Weinstein, Ph.D.
Anthony J. Broccoli, Ph.D.
Mark G. Robson, Ph.D.
David A. Vaccari, Ph.D., P.E.
Lily Young, Ph.D.

December 30, 2015

The following report has been issued by the Science Advisory Board to the Commissioner of the
New Jersey Department of Environmental Protection

Response to the Charge Questions regarding:

Microplastics and Nanoplastics

This report was initially prepared by the Public Health Standing Committee and sent to the Science
Advisory Board for review. The Science Advisory Board based this final report on those
recommendations from the Public Health Standing Committee.

Member of the Public Health Standing Committee include:

Mark Robson, Ph.D., M.P.H., Chairperson

Michael Greenberg, Ph.D.

Gerald Kennedy, M.S.

Howard Kipen, M.D., M.P.H.

Judith Klotz, Dr.P.H.

Mark Maddaloni, Dr.P.H.

Steven Marcus, M.D.

Clifford Weisel, Ph.D.

Final report on the Public Health Standing Committee's project on microplastics

NJDEP SAB Public Health Standing Committee (PHSC) Response to Charge Questions on Human Health Impacts of Microplastics and Nanoplastics

Executive Summary

There were three related charge questions dealing specifically with microplastics and nanoplastics:

1. What are the routes of human exposure?
2. What does the current science indicate in terms of adverse human health effects?
3. Is this issue a concern for New Jersey?

Plastic debris is a global concern, particularly for aquatic environments. This debris has the potential to breakdown into microscopic or nanoscopic particles. The resulting microplastics and nanoplastics may be ingested by a variety of aquatic organisms. Due to their small size and ability to adsorb and subsequently release chemicals, microplastics (<5 mm) and nanoplastics (<0.1 μm) pose a threat to these organisms. Human health may ultimately be affected due to the transfer of these plastics and/or contaminant chemicals (e.g., adsorbed pollutants, plastic additives) through the food web. Due to the emerging nature of microplastics and nanoplastics, human information is lacking for exposure and health effects. Current environmental measurements and ecological information support the possibility that humans may be exposed to microplastics or nanoplastics via oral, inhalation, and dermal routes. Recommendations are made to better characterize the occurrence of microplastics in New Jersey media (e.g., water and sediment) and aquatic species as well as the routes of human exposure (e.g., fish consumption and drinking water) in New Jersey. The current state of science regarding microplastics and nanoplastics, specifically with reference to ecological effects, suggests that it is plausible that human exposures are occurring, and may lead to adverse health effects. Because of this plausibility, recommendations are made to monitor future research for direct evidence of human health effects as well as research in other relevant areas (e.g., ecological observations, nanoparticle toxicology) and to identify susceptible human populations (e.g. life-stages). Taking into account New Jersey-specific considerations, the lack of New Jersey-specific data, and general unknowns (e.g., potential human health effects), microplastics and nanoplastics are a putative issue for New Jersey. Due to many data gaps at this time, it is recommended that the significance of microplastics and nanoplastics be considered relative to current environmental issues in New Jersey. It is also recommended that the issue be re-visited as additional information, particularly with relevance to New Jersey, becomes available for microplastics and nanoplastics.

Glossary

Bioaccumulation – the total uptake of a substance (e.g., a chemical pollutant) by an organism from various sources (e.g., food, sediment) as well as water (i.e., bioconcentration)

Biomagnification – a process where bioaccumulation causes an increase in total body burden (e.g., of a chemical pollutant) through a series of prey-predator relationships (i.e., up the food chain)

Ex vivo – the use of materials (e.g., cells or tissues) after removing from an organism while these materials remain viable

Fourier transform infrared spectroscopy – analytical technique where a sample (e.g., a microplastic particle of unknown polymer composition) is subjected to infrared radiation, the resulting molecular response of the sample is then mathematically translated (i.e., Fourier transformation) into a graphical representation (a spectrum) that can be interpreted by an analyst for the identification or quantification of the sample

Macroplastic – a piece of plastic with a diameter of >5 mm

Micro – a millionth part of a unit (designated as a prefix by the Greek letter, μ)

Microbeads – microplastic particles used as an abrasive in personal care products (e.g., facial and body scrubs, toothpaste), often composed of polyethylene or polypropylene and can be spherical in shape or of irregular shape

Microplastic – a piece of plastic with a diameter of <5 mm; see also nanoplastic

Nano – a billionth part of a unit (designated as a prefix by the letter, n)

Nanoparticle – a substance with at least one dimension between 1 and 100 nm, can be intentionally made (i.e., engineered nanoparticles) or be a by-product of combustion or natural processes

Nanoplastic – a piece of plastic with a diameter of <0.1 μm (i.e., <100 nm)

Neuston net – a net used in aquatic environments to capture organisms and debris floating near the surface of the water (i.e., the neustonic layer); these nets typically have a mesh size of ~300 μm

Nurdles – small pieces of plastic, which are typically in pellet form with a diameter of 1 to 5 mm, that are used to make finished plastic products

Trophic level – position of an organism within a food chain or food web

Charge Questions Addressed by the Public Health Standing Committee

New Jersey Department of Environmental Protection (NJDEP) Commissioner, Bob Martin tasked the Public Health Standing Committee (PHSC) of the NJDEP Science Advisory Board (NJDEP-SAB) with three broad charge questions relating to microplastics and nanoplastics:

- 1. What are the routes of human exposure?**
- 2. What does the current science indicate in terms of adverse human health effects?**
- 3. Is this issue a concern for New Jersey?**

History of Meetings

The initial meeting of the PHSC to address these charge questions, a face-to-face meeting at Rutgers/EOHSI, was on 10/21/14. The remaining meetings were teleconferences on 12/8/14, 2/23/15, 5/6/15, and 9/9/15.¹

The members of the PHSC consisted of:

Mark Robson, Ph.D., M.P.H. (PHSC Chair, Rutgers University)

Michael Greenberg, Ph.D. (Rutgers University)

Gerald Kennedy, M.S. (DuPont)

Howard Kipen, M.D., M.P.H. (Rutgers University)

Judith Klotz, Dr.P.H. (independent consultant)

Mark Maddaloni, Dr.P.H. (USEPA, Region 2)

Steven Marcus, M.D. (New Jersey Poison Information & Education System)

Clifford Weisel, Ph.D. (Rutgers University)

The following assisted the PHSC:

Brian Pachkowski, Ph.D., served as the NJDEP Division of Science, Research and Environmental Health liaison to the PHSC

Alan Stern, Dr.P.H. (Division of Science, Research and Environmental Health, NJDEP)

Nick Adams (intern, Rutgers University)

¹ Subsequent to the meeting on September 9, 2015, the Public Health Standing Committee, as a whole, voted to approve the report on microplastics and nanoplastics. However during the voting process, two members of the Standing Committee raised issues.

One member noted that there was no societal need for the inclusion of microplastics in consumer products and preferred the report include a statement that microplastics not be included in such products.

A second member stated that the qualification that any research efforts be weighed against other New Jersey priorities be more prominently highlighted in the overview and should precede the list of recommendations in Charge Question 1.

The Public Health Standing Committee's Approach to the Charge Questions

The Division of Science, Research and Environmental Health conducted literature searches using the PubMed, TOXLINE, and Web of Science databases to identify any relevant peer-reviewed literature. Additional resources (e.g., authoritative reports, legislation, grey literature) were obtained through manually scanning the reference sections of relevant peer-reviewed literature, periodic internet searches (e.g., Google), and by monitoring media reports regarding microplastics and nanoplastics. Relevant information obtained from these searches was distributed to the PHSC for group deliberations regarding the charge questions. Information presented herein is considered to be current as of September 2015.

The Public Health Standing Committee's Findings, Responses, and Recommendations

The findings, responses, and recommendations of the PHSC are presented below. In order to address the assigned charge questions and to consider mitigation of potential threats to human health posed by microplastics and nanoplastics (herein also collectively referred to as either “micro/nanoplastics” or “microscopic plastic debris”), general findings are first presented regarding the underlying nature and sources of these plastics in the environment. For each charge question, key findings are presented and include points of discussion and consideration as well as in-depth elaborations of the general findings, as needed. These key findings were then used to inform the specific responses to the charge questions and recommendations to NJDEP. Herein, when possible and as supported by the literature, observations specific to either microplastics or nanoplastics are noted as such.

General Findings

Literature

The PHSC initially noted the extent of micro/nanoplastics literature, particularly in regards to human health. Literature searches using the PubMed, TOXLINE, and Web of Science databases identified approximately 100 peer-reviewed references during the course of this project. The main focus of these references was environmental measurement or the ecological effects of micro/nanoplastics. Such research focused more on microplastics than on nanoplastics. No research was identified either through the aforementioned literature databases or internet searches that directly assessed either human exposure to or human health effects of micro/nanoplastics in the environment.

Considering that scientific interest in micro/nanoplastics has emerged only recently (Halden 2015), a lack of information on exposure and health effects for humans is not surprising. The paucity of human exposure and health effects information has also been noted by others investigating micro/nanoplastics (Bouwmeester et al., 2015; Galloway 2015; Seltnerich 2015; USEPA 2015). Due to this lack of human data, information regarding ecological effects of micro/nanoplastics and more generic research on nanoparticle toxicity were considered when addressing the charge questions.

Physical description of microscopic plastic debris

Microplastics are generally defined as having a diameter of <5 mm, whereas nanoplastics have a diameter of <0.1 µm (Arthur et al., 2009; Hollman et al., 2013). Micro/nanoplastics can be composed of the

following types of polymers: polyethylene, polypropylene, polyethylene terephthalate, polystyrene, polyvinyl chloride, polyester, polyacrylates, and nylon (Cole et al., 2011; Hollman et al., 2013). Microplastics can be in the shape of microbeads or spheres, fragments, fibers, and granules (Cole et al., 2011). The shapes of nanoplastics in the environment are relatively unknown, as methods to detect these nano-sized polymers in the environment currently do not exist (Koelmans et al., 2015).

Potential hazards of microscopic plastic debris

Because of their size, chemical composition, and physical properties, micro/nanoplastics can affect aquatic organisms and potentially human health. Adverse effects from micro/nanoplastics may result from a combination of the plastic's intrinsic toxicity (e.g., physical damage); chemical composition (e.g., monomeric units and additives); and ability to adsorb, concentrate, and release environmental pollutants (Browne et al., 2007; Hollman et al., 2013; Bouwmeester et al., 2015). Additionally, microplastics can serve as a vector for pathogens, potentially carrying microbial species to non-native waters (Zettler et al. 2013). Conversely, information could not be readily identified about the ability of nanoplastics to harbor pathogens. As microplastics have been detected in various trophic levels, there is concern that this debris or adsorbed chemicals may bioaccumulate in lower trophic levels. Furthermore, as organisms in these lower trophic levels are consumed, biomagnification may potentially occur in higher trophic levels, thereby affecting human health (Rochman, 2015). It is unclear whether similar processes would also occur in the environment with nanoplastics, as the transport of nanoplastics between organisms has only been observed in the laboratory (reviewed in Bouwmeester et al., 2015).

Formation of microscopic plastic debris

A number of human activities potentially introduce micro/nanoplastics into the environment. Examples of such activities include the improper disposal of plastics and the intentional use of microscopic plastic particles for personal and industrial uses (reviewed in Bouwmeester et al., 2015). Microplastics may also enter the environment as synthetic fibers (e.g., polyester) shed during clothes washing (Browne et al., 2011). Microscopic plastic debris can be designated as being either primary or secondary (Browne et al., 2007; Cole et al., 2011). Primary microplastics are manufactured at the microscopic level for use as abrasives in domestic products (e.g., microbeads in facial scrubs) and in industrial applications (e.g., media for air-blasting machinery or boat hulls). Additionally, primary microplastics in the form of pre-production pellets (i.e., nurdles) are manufactured for the production of larger plastic products (Seltenrich, 2015). Secondary microplastics form by the photolytic, mechanical, or biological degradation of large plastic items (i.e., macroplastics) that are already present in the environment. Similar to microplastics, nanoplastics can be intentionally manufactured for a variety of uses (e.g., electronics, medical products, and paints) or can be potentially formed by the fragmentation or degradation of macroplastics or microplastics (Koelmans et al., 2015).

Measurement of microscopic plastic debris

Methods have been established to identify and quantify microplastics in water, sediments, and some organisms (e.g., copepods). A number of reviews and technical resources discuss the various methods in current practice (Bouwmeester et al., 2015; Cole et al., 2014; Hidalgo-Ruz et al., 2012; Masura et al., 2015; Rocha-Santo and Duarte, 2015). As a generic example, sampling methods at the water surface rely on collecting microplastics using neuston nets (~0.3 mm mesh size) followed by the digestion (e.g., wet peroxide oxidation) of any collected organic material. Following the further removal of any residual organic material by density separation, the collected microplastics are manually identified during a

microscope examination and then weighed to determine concentration (Masura et al., 2015). Spectroscopic techniques (e.g., Fourier transform infrared spectroscopy) can further identify the types of plastic polymers (e.g., polyethylene, polystyrene) collected. Conversely, methods for detecting nanoplastics in the environment are relatively lacking (Bouwmeester et al., 2015; Koelmans et al., 2015). However, methods to detect engineered nanomaterials (e.g., metal oxides) may be potential approaches for measuring nanoplastics in different environmental media (Bouwmeester et al., 2015).

Microbeads in personal care products

An important source of microplastics in the environment is the use of microbeads in personal care products. Typically composed of polyethylene, such microbeads are used as exfoliants or for aesthetics in facial cleansers, soaps, or toothpastes (Fendall and Sewell, 2009; Verschoor et al., 2014). A sampling of commercially available facial cleansers demonstrated that microbeads can have a median size range from 0.2 to 0.4 mm (Fendall and Sewell, 2009). After product use, microbeads are washed down the drain and enter wastewater treatment systems. In the State of New York alone, an estimated 19 tons of microbeads from personal care products may enter New York wastewater treatment plants each year (Nalbone, 2014). Due to the size of these plastics, wastewater treatment systems do not remove all microscopic plastic debris allowing for their discharge into receiving waters (Nalbone, 2015). Conversely, those microbeads (or other microscopic plastic debris) removed by wastewater treatment plants may be retained in the sludge, which may then be used for land application.

Due to the common use of personal care products that contain microbeads, states such as Minnesota and New York have reviewed the current science on microbeads, and microplastics in general, to understand the potential environmental and human health impacts of microbeads (Lohse-Hanson et al., 2014; Nalbone, 2014). New Jersey has passed a law to ban the use of microbeads in personal care products (NJ Assem. Bill 3083). In addition, Illinois, Maine, Colorado, and Wisconsin have signed similar bills into law. In late December 2015, federal legislation was signed into law banning the use of plastic microbeads in personal care products (Microbead-Free Waters Act of 2015).

Charge Question 1: What are the routes of human exposure?

As potential correlates of routes of human exposure, key findings regarding environmental measurements and ecological observations were considered in responding to this charge question.

Key Findings

Microplastics in water

Environmental contamination with microplastics was first detected in the early 1970s in the Northwestern Atlantic Ocean (Carpenter et al., 1972; Colton et al., 1974). Since then, microplastic contamination has become a global issue with research primarily focusing on aquatic environments. Microplastic contamination has been detected in the world's oceans (Ivar do Sul and Costa, 2014) and Arctic Sea ice (Obbard et al., 2014). While not studied as frequently as in salt water, microplastics have been detected

in freshwater, including lakes (e.g., the Great Lakes; Eriksen et al., 2013), rivers (e.g., The North Shore Channel in Chicago; McCormick et al. 2014), and remote bodies of water (e.g., Lake Hovsgol, Mongolia; Free et al., 2014). Additionally, microplastics have been detected in aquatic sediments from around the world (reviewed in Ivar do Sul and Costa, 2014). Nanoplastics have not been detected in aquatic environments, due to limitations in current sampling technology (Bouwmeester et al., 2015; Koelmans et al., 2015).

At least 5 trillion pieces of plastics are estimated to be floating in the world's oceans, based on sampling of floating plastics (0.33 to >200 mm in size) and computer modeling. Of this estimate, over 90% are believed to be microplastics (Eriksen et al. 2014). Based on site-specific sampling, the abundance of microplastics varies by location and has been reported to range from 3 to 100,000 particles per m³ of seawater (reviewed in Wright et al., 2013). While not investigated as thoroughly, levels of microplastics in specific freshwater environments were reported to be of similar abundance (reviewed in Eerkes-Medrano et al. 2015). Population density is one factor that may influence the abundance of microplastics in aquatic environments (Browne et al. 2011; Yonkos et al. 2014).

Microplastics on land and in the air

While not studied as frequently as in aquatic environments, evidence suggests that microplastics can occur in terrestrial habitats and is present in the atmosphere. While some microplastics are able to pass through wastewater treatment plants (Nalbone 2015), a portion of the plastics are retained in the sewage sludge. If such contaminated sludge is applied to land (e.g., in agriculture), then microplastics may be found in terrestrial environments (Rillig 2012; Zubris and Richards 2005). Microplastics, in the form of fibers, were detected at an abundance of 29 to 280 particles/m²/day on an urban rooftop as a consequence of atmospheric fallout (Gasperi et al., 2015). Additionally, plastic fibers (i.e., polyester) have been found in human lung tissue (Pauly et al., 1998). The presence of microplastics, particularly fibers, in the atmosphere suggests further deposition onto soil and vegetation. No information was readily available assessing the occurrence of nanoplastics in terrestrial habitats or the atmosphere.

Ecological observations

Numerous laboratory and field studies have demonstrated microplastic contamination in plankton, aquatic invertebrates, and vertebrates, including fish and marine mammals (reviewed in Cole et al., 2001; Ivar do Sul and Costa, 2014). The presence of microplastics in lower trophic levels raises the possibility that microplastics and/or their contaminants (i.e., adsorbed or constituent chemicals) may be transferred up the food web, potentially to species consumed by humans (reviewed in Ivar do Sul and Costa, 2014; Lusher, 2015). Nanoplastics have not been detected in the tissues of organisms collected from the environment, due a lack of analytical methods (Bouwmeester et al., 2015; Koelmans et al., 2015). However, laboratory studies have demonstrated the ability of organisms (e.g., algae, mussels, and zooplankton) to take in nanoplastics (reviewed in Bouwmeester et al., 2015). As with microplastics, nanoplastics may potentially be transferred up the food web.

Microplastics have been found in marine species consumed by humans. For example, Van Cauwenberghe and Janssen (2014) determined the number of microplastics in farm-raised mussels and oysters purchased from the supermarket. Based on the number of microplastic particles found in these shellfish and European seafood consumption data, the authors calculated that humans consuming these species could be potentially exposed to up to 11,000 pieces of microplastics a year (Van Cauwenberghe

and Janssen, 2014). In field studies, microplastics have been found in the gastrointestinal tracts of finfish species including some species consumed by humans (reviewed in Lusher, 2015). Additionally, a laboratory study with finfish has demonstrated the ability of microplastic particles to translocate from the gastrointestinal tract to the liver (Avio et al., 2015). In the laboratory, mussels were able to ingest nanoplastics (reviewed in Bouwmeester et al., 2015). In addition to the presence of microplastics in edible species, microplastics have also been found in abiotic materials (e.g., table salts) that humans consume (Yang et al., 2015).²

In addition to the physical presence of microplastics in aquatic organisms, laboratory studies have demonstrated the bioaccumulation of chemicals in organisms fed microplastics with adsorbed contaminants (Browne et al. 2013; Rochman et al., 2013). This transfer of chemicals into organisms at lower trophic levels raises the possibility that such chemicals may biomagnify in top predators, including humans (Rochman, 2015). In the field, the consumption of prey contaminated with microplastics was suggested as a possible source of phthalates measured in whales (Fossi et al., 2012). While this observation implies the role of microplastics in transferring contaminants (e.g., phthalates) between species, other contaminated media (e.g., water, sediment, food) may be of equal or greater importance than plastics for chemical transfer in aquatic organisms (Gouin et al., 2011; Selden et al., 2015). For nanoplastics, a similar hypothesis exists where adsorbed chemicals may contribute to toxicity upon ingestion of these particles (Koelmans et al., 2015).

The Public Health Standing Committee's Response to Charge Question 1

Current environmental measurements and ecological information support the possibility that humans may be exposed to microplastics and possibly nanoplastics via oral, inhalation, and dermal routes. Humans may be directly exposed to microplastics and nanoplastics through the actual ingestion of these particles. Humans may also be exposed to the chemicals that are constituents (e.g., monomers) of or adsorbed to the plastics (i.e., indirect exposure from micro/nanoplastics). In either case, the possibility exists that microplastics or nanoplastics and/or contaminant chemicals may initially be ingested by lower trophic levels and bioaccumulate with potential biomagnification at higher trophic levels, which may lead to human exposure.

Oral exposure

The primary source of human exposure to micro/nanoplastics in the environment may be through oral exposure, either from food or potentially drinking water. Aquatic species contaminated with micro/nanoplastics (i.e., present in their gut or other tissues) may serve as an important source of human exposure. In the case of shellfish, humans consume these species whole, including the gut which can contain microscopic plastic debris. While the gastrointestinal tracts of finfish are not typically consumed by humans, some micro/nanoplastics may cross the gut into tissues ultimately consumed by humans.

The translocation of microplastics across the gut has been demonstrated in the laboratory for crabs and mussels (Brown et al., 2008; Watts et al., 2014). Additionally, other laboratory experiments have demonstrated the ability of microscopic particles (0.03 to 150 µm in size) of various compositions (i.e.,

² While published after the September 2015 literature cut-off date, Yang et al. (2015) was included based on comments made during the November 2015 full SAB meeting.

not just plastics) to cross the guts of different animal species (reviewed in Hussain et al., 2001). The presence of micro/nanoplastics in tissues beyond the gastrointestinal tract has yet to be assessed in finfish, especially those in the wild (Bouwmeester et al., 2015). Microplastics have, however, been observed in the livers of fish fed microplastics in a laboratory setting (Avio et al., 2015). Microplastics have been found on fish skin (Tang et al., 2015).

Microplastics have been detected in freshwater environments (e.g., the Great Lakes) used as sources of drinking water. This observation suggests that drinking water may be a source of human exposure, especially if water treatment processes cannot entirely remove microscopic plastic debris, particularly nanoplastics.

In addition to oral exposure to actual micro/nanoplastic particles, the potential exists for humans to also be exposed to any chemicals that are released from the plastic into the media (i.e., aquatic organism, water) being consumed, thereby representing an indirect exposure from micro/nanoplastics.

Inhalation exposure

Human exposure to micro/nanoplastics via inhalation is speculated to occur after micro/nanoplastics become airborne, potentially as a result of wave action in aquatic environments or from the application of wastewater treatment sludge in agriculture. If micro/nanoplastics are able to escape drinking water treatment, inhalation exposure may occur during showering. Additionally, microplastics have been detected in atmospheric fallout suggesting another possible source of inhalation exposure.

Dermal exposure

Dermal contact may occur when humans interact with water contaminated with micro/nanoplastics. However due to the size of microplastics, absorption through the skin is not expected to occur. Nanoplastics are not expected to penetrate into or through human skin due to their insolubility in water.

The Public Health Standing Committee's Recommendations for Charge Question 1

General recommendation

- As methods to monitor human exposure to micro/nanoplastics do not currently exist, research should initially focus on ecological exposures, which may ultimately lead to human exposures. However, opportunities exist to consider future research regarding human exposure.

Ecological exposure

- The occurrence of microplastics in New Jersey environmental media (e.g., marine, estuary, freshwater, aquatic sediment) should be determined, as methods for detection are currently available. For nanoplastics, it should be noted that technologies for measuring this type of plastic debris (i.e., <0.1 μm in size) are generally lacking (Bouwmeester et al., 2015; USEPA, 2015).
- The occurrence of microplastics should be determined in aquatic species (e.g., finfish and shellfish) harvested and/or consumed in New Jersey, as dictated by current methodology.
- Methods should be developed to further assess the occurrence of micro/nanoplastics in environmental media and biota. For example, methods are needed to determine the presence of micro/nanoplastics

in finfish tissue (e.g., edible tissue beyond the gastrointestinal tract) and methods are needed to detect nanoplastics in the environment.

- Microplastics found in New Jersey environmental media or aquatic species should be characterized in order to determine whether these plastics have any properties (e.g., polymer type or size, mixture of adsorbed chemicals) that are different than those properties of microplastics found elsewhere in the world.
- Ongoing microplastic research, both specific to New Jersey and in general, should be monitored as a means to potentially address the above recommendations. Examples of ongoing research specific to New Jersey include sampling efforts by the NY/NJ Baykeeper (2015) and Clean Ocean Action (2014).

Human exposure

- Methods for determining human exposure to physical pieces of micro/nanoplastics should be explored and developed if feasible.
- Drinking water treatment processes should be assessed to determine whether they can remove micro/nanoplastics.
- Susceptible New Jersey populations should be identified in terms of differential exposure (e.g., through subsistence fishing versus occasional fish consumption) to micro/nanoplastics.
- The ability of micro/nanoplastics to become airborne due to wave action should be determined.
- Research should be monitored regarding the ability of micro/nanoplastics and/or contaminant chemicals (e.g., adsorbed pollutants, monomers, additives) to biomagnify in higher trophic levels, including humans.

Charge Question 2: What does the current science indicate in terms of adverse human health effects?

No literature was identified that directly investigated human health effects due to exposure to micro/nanoplastics in the environment. However, key findings regarding ecological observations and nanoparticle toxicology were considered in responding to this charge question.

Key Findings

Toxicological considerations of microplastics and nanoplastics

A number of the chemical and physical properties, either alone or in combination, of micro/nanoplastics support the notion that exposure to these particles can result in a toxic effect (Browne et al., 2007; Hollman et al., 2013; Koelmans et al., 2015). The physical presence of microplastics may be toxic due to their inherent ability to damage an organism through intestinal blockage or tissue abrasion (Wright et al., 2013). The toxicity of nanoplastic particles may be dependent on their ability to translocate across the gut, enter systemic circulation, penetrate cells, and interact with biological macromolecules, such as lipids and protein (Bouwmeester et al., 2015). Plastics are composed of monomers, such as bisphenol A,

styrene, and vinyl chloride, as well as additives including plasticizers (phthalates), antimicrobials (triclosan), and flame retardants (polybrominated diphenyl ethers). If released from plastics, these monomers and additives may have toxic effects on wildlife and humans (Browne et al., 2007; Cole et al., 2011).

Micro/nanoplastics may serve as a vector for exposure to environmental chemicals. Due to their high surface area to volume ratio and hydrophobicity, microplastics and nanoplastics can adsorb and concentrate environmental contaminants, such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and organochlorine pesticides (Engler, 2012; Hollman et al., 2013; Koelmans et al., 2015). Metals, such as cadmium, chromium, and lead, have also been detected on microplastics collected from a marine environment (Rochman et al., 2014). Additionally, microplastics can serve as a substrate for microbial communities (i.e., the “Plastisphere”) and can be considered a vector for exposure to potential pathogens (McCormick et al., 2014; Zettler et al., 2013). Although not empirically demonstrated for nanoplastics, observations of metal adsorption on microplastics suggest similar phenomena in nanoplastics. The size of nanoplastics (i.e., smaller than bacteria and most viruses) may preclude them from being vectors for pathogens.

Ecological effects

Following microplastic or nanoplastic ingestion during laboratory experiments, adverse effects have been reported in a variety of organisms (reviewed in Eerkes-Medrano et al., 2015; Lusher, 2015). At lower trophic levels, for example in algae, decreased photosynthesis and an increase in reactive oxygen species production have been observed with nanoplastic exposure. Decreases in feeding, energy, and lipid reserves as well as an increase in oxidative stress have been reported in worms with exposure to microplastics.

Effects have also been observed in higher trophic levels (reviewed in Eerkes-Medrano et al., 2015; Lusher, 2015). For example, upon ingestion by blue mussels, microplastics were able to translocate to the lymph system and cause an immune response. Fish (common goby) exposed to microplastics and pyrene experienced modulation of the bioavailability or biotransformation of pyrene, a decrease in energy production, and inhibition of acetylcholinesterase activity (microplastic-only exposure). Additional studies in fish (Japanese medaka) have reported hepatic stress (e.g., glycogen depletion, cellular alterations) and alterations in gene expression, which were suggestive of endocrine disruption, following exposure to microplastics with or without contamination with environmental pollutants. As reviewed in Koelman et al. (2015), laboratory experiments with nanoplastics have reported reduced filter feeding in mussels, toxicity and changes in gene expression in sea urchin embryos, and effects on lipid metabolism and behavior in carp.

Consideration of proxy materials to inform the human health effects of micro/nanoplastics

The toxicology of nanoparticles (other than nanoplastics) may offer some insight into the biological and chemical factors that may be involved with the potential human health effects following exposure to micro/nanoplastics in the environment. In this sense, nanoparticles may serve as a proxy for micro/nanoplastics. Such an approach has been advocated or explored to varying degrees by other efforts attempting to address the human health effects of micro/nanoplastics (Bouwmeester et al., 2015; Galloway, 2015; Hollman et al., 2013; Leslie et al., 2011; Seldenrich, 2015; Syberg et al., 2015).

For clarity herein, microplastics and nanoplastics are distinct from nanoparticles that have, to date, been represented in the toxicological literature. The plastics are defined as synthetic polymers (e.g., polystyrene, polyethylene), whereas the nanoparticles are substances such as carbon nanotubes, silicon dioxide, or metal-based nanoparticles (e.g., titanium dioxide).

In order to identify relevant nanoparticle information, the PHSC conducted a PubMed search that specifically focused on a broad, yet relevant endpoint (i.e., human health) and oral exposure (the presumptive main route of exposure for micro/nanoplastics). There were 13 review articles and 10 primary research articles that were identified and deemed relevant to this proxy approach. The PHSC reviewed the nanoparticle articles to identify any generalizations, characteristics, health effects, or other salient information that may also apply to identifying the adverse human health effects of micro/nanoplastics in the environment. For example, it was noted during a PHSC deliberation that the authors of one review article (O'Brien and Cummins, 2010) had concluded that the release of nanoparticles into the environment may pose greater ecological risks than risks to human health. Additionally from this PHSC discussion of the relevant nanoparticle literature, the members of the PHSC noted the following observations.

- There was on-going controversy in the literature regarding the predominant driver for the toxicity of nanoparticles: chemistry, versus size, versus shape of the particle.
- Some of the effects mentioned to occur following exposure to nanoparticles include: cardiopulmonary effects, changes in endogenous metabolites, effects on blood, genotoxicity, inflammatory response, interference with nutrient absorption and gut microflora, oxidative stress, and reproductive effects.
- Nanoparticle toxicity is complex and dictated by a number of factors including dose or concentration, charge, duration of exposure, solubility, shape, size, and surface area.
- With oral exposure, systemic distribution was reported to occur. However, there is likely minimal toxicity from dermal exposure to nanoparticles (e.g., from the application of cosmetics).
- Contamination of some nanoparticles (e.g., the contamination of carbon nanotubes with metals) may confound observations of toxicity.

Similar to the above approach by the PHSC, a systematic approach has been recently proposed for assessing the potential ecological hazards of microplastics (Syberg et al., 2015). With nanoparticle toxicology as a basis, this proposed approach identifies parallels (e.g., particle factors) between engineered nanoparticles and microplastics (see Table 1). While originally intended for ecological risks, this proposed approach may also be applicable for identifying possible human health effects of micro/nanoplastics.

Table 1. Parallels between engineered nanoparticles and microplastics		
	Nanoparticle	Microplastic
Particle factors	Importance of: • Metal composition • Shape • Size (micro- vs nano-sized)	Importance of: • Plastic constituent • Shape • Size
Environmental behavior	• Aging and weather of nanoparticles • Adsorption of contaminants	• Changes to surface properties through environmental processes • Potential to adsorb contaminants
Interaction with organisms	• Endocytosis • Impairment of digestive processes	• Cellular uptake and intracellular effects • Physical damage following ingestion
Adapted from Syberg et al., 2015		

While not intended to address the human health effects of micro/nanoplastics in the environment, modified (e.g., fluorescently labeled) polystyrene nanoparticles have been used as a model in research on drug delivery and nanoparticle inhalation (e.g., air pollution) in mammalian systems (Frohlich et al., 2009). As reviewed in Leslie et al. (2011), polystyrene particle literature may be particularly informative as research on human-based cell lines and systems have demonstrated the uptake of micro- and nano-sized polystyrene particles by lung cells and an *ex vivo* human placental model. Additionally, such particles were reported to cause cellular effects, such as decreased contractility and the induction of apoptosis and necrosis.

The Public Health Standing Committee’s Response to Charge Question 2

The current state of science regarding micro/nanoplastics, specifically with reference to ecological effects, suggests that it is plausible that human exposure to environmental micro/nanoplastics may cause adverse health effects.

Based on the general toxicological considerations of micro/nanoplastics (i.e., physical damage, chemical exposures), it is reasonable to speculate that human exposure to micro/nanoplastics could have impacts at the molecular and cellular levels. Although observed in lower organisms (e.g., fish) following micro/nanoplastics exposure, effects like inflammation and the production of reactive oxygen species are plausible human cellular reactions to toxic insults. Laboratory studies using polystyrene particles have demonstrated the uptake and effect of plastic particles on human-based models. However, since there are no human empirical data (e.g., epidemiological) or mammalian (e.g., rodent) data assessing any effects of environmental micro/nanoplastics, predicting any resulting pathology or disease states from these molecular and cellular events is difficult. Additionally, the assessment of human health effects of microplastics would likely need to be done separately from nanoplastics due to potential size-dependent differences in absorption across the human gut (Bouwmeester et al., 2015).

The comprehensive identification and review of relevant factors (e.g., physical and chemical properties) and mechanisms of nanoparticle toxicity and their extrapolation to human health effects of micro/nanoplastics is beyond the scope of the PHSC's current charge. However, opportunities exist for conducting future research, particularly from relevant literature, to assess potential human health effects.

The Public Health Standing Committee's Recommendations for Charge Question 2

- While research that directly assesses the human health effects of micro/nanoplastics in the environment is not likely to be immediately available, going forward, the peer-reviewed literature should be monitored.
- Research on areas relevant to micro/nanoplastics (e.g., ecological observations, nanoparticle toxicology) should be monitored to better inform the potential human health effects of these plastics.
- Based on current knowledge of the chemical and physical characteristics of micro/nanoplastics, susceptible human populations (e.g., life-stages) should be identified that may be at increased risk for health effects following exposure to these plastics.

Charge Question 3: Is this issue a concern for New Jersey?

No information was identified that specifically assessed the micro/nanoplastic issue in New Jersey. However, key findings regarding the general observations for micro/nanoplastics, as discussed in the previous charge questions, and New Jersey-specific considerations, particularly regarding aquatic environments, were considered in responding to this charge question.

Key Findings

In addition to the global nature of plastic debris in the environment, a number of other considerations specific to New Jersey may increase the significance of the micro/nanoplastic issue for New Jersey.

Plastic debris and New Jersey

Plastics have been an on-going issue for New Jersey. The first measurements of microplastics in the environment, which occurred in the early 1970s, detected this debris in the Atlantic Ocean, including off the coast of New Jersey (Carpenter et al., 1972; Colten et al., 1974). Nearly 40 years later, microplastics were still present in the Atlantic Ocean off the coast of New Jersey (Law et al., 2010). In addition, the presence of larger pieces of plastic debris, which may degrade or fragment into micro/nanoplastics, is a known phenomenon in New Jersey (Ribic, 1998).

Potential areas of contamination in New Jersey

New Jersey has a variety of aquatic environments, including ocean shoreline, estuaries, and rivers that have the potential to become contaminated with microplastics and nanoplastics. The ability of

microplastics to contaminate each of these types of environments has been documented, based on sampling from other geographic regions (reviewed in Eerkes-Medrano et al., 2015 and Lusher, 2015).

Population density

Population density is a factor that may influence the abundance of microplastics in aquatic environments (Browne et al., 2011; Yonkos et al., 2014). New Jersey has the highest population density in the United States and is in proximity to highly populated cities (i.e., New York City and Philadelphia) in neighboring states. These observations suggest that the micro/nanoplastics issue may be of particular concern for New Jersey.

Microplastics originating from other locations

Options exist to potentially limit New Jersey's own contribution of microplastics that enter the state's environments (e.g., banning microbeads or other plastic products). However, New Jersey likely receives micro/nanoplastics from non-New Jersey sources, such as neighboring states or other geographic regions. For example, wastewater treatment plants in the State of New York discharge effluent, which has been demonstrated to contain microplastics, into receiving waters that are of significance to New Jersey, including the Delaware and Hudson Rivers and the Atlantic Ocean (Nalbone, 2015). The ability of microplastics and possibly nanoplastics to serve as vectors for environmental chemicals and microbes, coupled with the ability of this debris to be transported across bodies of waters, raises the possibility for New Jersey exposures to chemicals or microbes originating elsewhere.

Commercial and recreational fishing in New Jersey

A number of aquatic species are consumed by New Jersey residents and/or are commercially important for New Jersey. Shellfish species relevant to New Jersey, such as blue mussels and oysters, have been shown to consume microplastics (Van Cauwenberghe and Janssen, 2014). Additionally, microplastics have been observed in the gastrointestinal tracts of finfish (reviewed in Lusher, 2015), some of which may be harvested from New Jersey waters. While these observations are currently based on measurements from other geographic locations, the presence of microplastics in such species in New Jersey could represent an exposure and potential hazard to humans. Additionally, mussels were able to ingest nanoplastics in the laboratory (reviewed in Bouwmeester et al., 2015).

The New Jersey ban on microbeads

In March 2015, New Jersey became the second state to pass legislation banning microbeads in personal care products. By "prohibiting the manufacture, sale or promotion of personal care products containing microbeads" (NJ Assem. Bill 3083), this ban aims to limit the introduction of microplastics, specifically in the form of plastic microbeads, into the environment. However, two scientific issues exist regarding the ability of this law to protect New Jersey waters. Even with a ban on microbeads in New Jersey, sources of microplastics will still exist, including the continual degradation of plastics already in the environment, the contribution of microbeads from neighboring states, and the shedding of synthetic fibers during clothes washing. Additionally, the New Jersey law defines the microbeads to be banned as "non-biodegradable" (NJ Assem. Bill 3083). With this definition, personal care products could still contain microbeads that are biodegradable. However, the potential for biodegradable microbeads to completely degrade in certain conditions, such as marine environments, is unclear (CalRecycle, 2012).

The Public Health Standing Committee's Response to Charge Question 3

Taking into account New Jersey-specific considerations, the lack of New Jersey-specific data, and other general unknowns (e.g., potential human health effects), micro/nanoplastics are a putative issue for New Jersey.

Micro/nanoplastics are contaminants of emerging concern for which a number of research questions have yet to be addressed (USEPA, 2015), for the topic in general and with regards to New Jersey. Interest in researching microplastics is fairly recent, as concern for this contaminant started in 2008. This interest, as reflected by annual publishing activity, is projected to peak around 2020 (Halden, 2015).

As human exposures to micro/nanoplastics in New Jersey and human health effects are uncertain, further research should provide a more definitive answer regarding the extent of this issue for New Jersey. In the interim, other environmental issues may be a more pressing concern for New Jersey.

The Public Health Standing Committee's Recommendations for Charge Question 3

- The micro/nanoplastics issue is an environmental concern that should be put into perspective relative to other on-going or emerging environmental concerns in New Jersey.
- Addressing the research recommendations from charge questions 1 and 2 through NJDEP-based funding should be considered in order to more clearly understand the micro/nanoplastics issue in New Jersey.
- The micro/nanoplastics issue should be re-visited as additional information becomes available regarding their specific presence in New Jersey environmental media and biota as well as any general and New Jersey-specific observations of human exposures and human health effects.

References

Arthur C, Baker J, Bamford H. 2009. Proceedings of the international research workshop on the occurrence, effects and fate of microplastic marine debris. Sept 9-11, 2008. NOAA Technical Memorandum NOS-OR&R-30.

Avio CG, Gorbi S, Regoli F. 2015. Experimental development of a new protocol for extraction and characterization of microplastics in fish tissues: first observations in commercial species from Adriatic Sea. Marine Environmental Research. Epub date July 02, 2015.

Bouwmeester H, Hollman PCH, Peters RJB. 2015. Potential health impact of environmentally released micro- and nanoplastics in the human food production chain: experiences from nanotoxicology. Environmental Science & Technology. Epub date July 01, 2015.

Browne MA, Galloway T, Thompson R. 2007. Microplastic--an emerging contaminant of potential concern? Integrated Environmental Assessment and Management. 3:559-561.

- Browne MA, Dissanayake A, Galloway TS, Lowe DM, Thompson RC. 2008. Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis* (L). *Environmental Science & Technology*. 42:5026-31.
- Browne MA, Crump P, Niven SJ, Teuten E, Tonkin A, Galloway T, et al. 2011. Accumulation of microplastic on shorelines worldwide: sources and sinks. *Environmental Science & Technology*. 45:9175-9179.
- Browne MA, Niven SJ, Galloway TS, Rowland SJ, Thompson RC. 2013. Microplastic moves pollutants and additives to worms, reducing functions linked to health and biodiversity. *Current Biology*. CB 23:2388-2392.
- CalRecycle. 2012. PLA and PHA biodegradation in the marine environment. California Department of Resources Recycling and Recovery. Publication # DRRR-2012-1435. Available at: <http://www.calrecycle.ca.gov/Publications/Documents/1435/20121435.pdf>. Accessed July 06, 2015.
- Carpenter EJ, Anderson SJ, Harvey GR, Miklas HP, Peck BB. 1972. Polystyrene spherules in coastal waters. *Science*. 178:749-750.
- Clean Ocean Action. 2014. Microplastic research agenda 2014-16. Available at: http://www.cleanoceanaction.org/fileadmin/editor_group2/Education/COA_Microplastics_Research_Agenda_updated_4_2015.pdf. Accessed June 22, 2015.
- Cole M, Lindeque P, Halsband C, Galloway TS. 2011. Microplastics as contaminants in the marine environment: a review. *Marine Pollution Bulletin*. 62:2588-2597.
- Cole M, Webb H, Lindeque PK, Fileman ES, Halsband C, Galloway TS. 2014. Isolation of microplastics in biota-rich seawater samples and marine organisms. *Scientific Reports*. 4:4528.
- Colton JB, Jr., Burns BR, Knapp FD. 1974. Plastic particles in surface waters of the Northwestern Atlantic. *Science*. 185:491-497.
- Eerkes-Medrano D, Thompson RC, Aldridge DC. 2015. Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. *Water Research*. 75:63-82.
- Engler RE. 2012. The complex interaction between marine debris and toxic chemicals in the ocean. *Environmental Science & Technology*. 46:12302-15.
- Eriksen M, Mason S, Wilson S, Box C, Zellers A, Edwards W, et al. 2013. Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Marine Pollution Bulletin*. 77:177-182.
- Eriksen M, Lebreton LC, Carson HS, Thiel M, Moore CJ, Borerro JC, et al. 2014. Plastic pollution in the world's oceans: More than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PloS One*. 9:e111913.
- Fendall LS, Sewell MA. 2009. Contributing to marine pollution by washing your face: microplastics in facial cleansers. *Marine Pollution Bulletin*. 58:1225-1228.

- Fossi MC, Panti C, Guerranti C, Coppola D, Giannetti M, Marsili L, et al. 2012. Are baleen whales exposed to the threat of microplastics? a case study of the Mediterranean fin whale (*Balaenoptera physalus*). *Marine Pollution Bulletin*. 64:2374-2379.
- Free CM, Jensen OP, Mason SA, Eriksen M, Williamson NJ, Boldgiv B. 2014. High-levels of microplastic pollution in a large, remote, mountain lake. *Marine Pollution Bulletin*. 85:156-163.
- Frohlich E, Samberger C, Kueznik T, Absenger M, Roblegg E, Zimmer A, et al. 2009. Cytotoxicity of nanoparticles independent from oxidative stress. *The Journal of Toxicological Sciences*. 34:363-375.
- Galloway TS. 2015. Micro- and nano-plastics and human health. In M. Bergmann, L. Gutow & M. Klages (eds.), *Marine Anthropogenic Litter* (pp. 343-366). Springer: Berlin.
- Gasperi J, Rachid D, Rocher V, Tassin B. 2015. Microplastics in the continental area: an emerging challenge. *Norman Bulletin*. 4:18-19.
- Gouin T, Roche N, Lohmann R, Hodges G. 2011. A thermodynamic approach for assessing the environmental exposure of chemicals absorbed to microplastic. *Environmental Science & Technology*. 45:1466-1472.
- Halden RU. 2015. Epistemology of contaminants of emerging concern and literature meta-analysis. *Journal of Hazardous Materials*. 282:2-9.
- Hidalgo-Ruz V, Gutow L, Thompson RC, Thiel M. 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. *Environmental Science & Technology*. 46:3060-75.
- Hollman PCH, Bouwmeester H, Peters RJB. 2013. Microplastics in the aquatic food chain: sources, measurements, occurrence and potential health risks. Wageningen, RIKILT Wageningen UR (University & Research Centre), RIKILT report 2013.003.
- Hussain N, Jaitley V, Florence AT. 2001. Recent advances in the understanding of uptake of microparticulates across the gastrointestinal lymphatics. *Advanced Drug Delivery Reviews*. 50:107-142.
- Ivar do Sul JA, Costa MF. 2014. The present and future of microplastic pollution in the marine environment. *Environmental Pollution*. 185:352-364.
- Koelmans AA, Besseling E, Shim WJ. 2015. Nanoplastics in the aquatic environment: critical review. In M. Bergmann, L. Gutow & M. Klages (eds.), *Marine Anthropogenic Litter* (pp. 325-340). Springer: Berlin.
- Law KL, Morét-Ferguson S, Maximenko NA, Proskurowski G, Peacock EE, Hafner J, Reddy CM. 2010. Plastic accumulation in the North Atlantic subtropical gyre. *Science*. 329:1185-8.
- Leslie HA, van der Meulen MD, Kleissen FM, Vethaak AD. 2011. Microplastic litter in the Dutch marine environment. IVM Institute for Environmental Studies. Available at: http://www.ivm.vu.nl/en/Images/Deltares-IVM%20rapport%20microplastics-2_tcm53-409861.pdf. Accessed August 28, 2014.

Lohse-Hanson C, Skuta G, Kessler K. 2014. Plastic microbeads in Minnesota. Minnesota Pollution Control Agency. Document number: lrwq-s1sy14.

Lusher A. 2015. Microplastics in the marine environment: distribution, interactions and effects. In M. Bergmann, L. Gutow & M. Klages (eds.), *Marine Anthropogenic Litter* (pp. 343-366). Springer: Berlin.

Masura J, Baker J, Foster G, Arthur C. 2015. Laboratory methods for the analysis of microplastics in the marine environment: recommendations for quantifying synthetic particles in waters and sediments. NOAA Technical Memorandum NOS-OR&R-48.

McCormick A, Hoellein TJ, Mason SA, Schluep J, Kelly JJ. 2014. Microplastic is an abundant and distinct microbial habitat in an urban river. *Environmental Science & Technology* 48:11863-11871.

Microbead-Free Waters Act of 2015, HR 1321, 114th Cong, 1st Sess (2015). Available at: <https://www.congress.gov/bill/114th-congress/house-bill/1321/text>. Accessed December 30, 2015.

Nalbone J. 2014. Unseen threat: how microbeads harm New York waters, wildlife, health and environment. Environmental Protection Bureau of the New York State Attorney General's Office. Available at: http://ag.ny.gov/pdfs/Microbeads_Report_5_14_14.pdf. Accessed August 27, 2014.

Nalbone J. 2015. Discharging microbeads to our waters: an examination of wastewater treatment plants in New York. Environmental Protection Bureau of the New York State Attorney General's Office. Available at: http://www.ag.ny.gov/pdfs/2015_Microbeads_Report_FINAL.pdf. Accessed April 20, 2015.

New Jersey Assembly. Bill 3083, 2015, approved March 23, 2015, Title: Prohibits manufacture, sale or promotion of personal care products containing microbeads. Available at: <https://legiscan.com/NJ/text/A3083/2014>. Accessed July 13, 2015.

New York/New Jersey Baykeeper. 2015. Reducing plastic pollution in our waterways. Available at: <http://nynjbaykeeper.org/plastic-reduction/>. Accessed July 06, 2015.

O'Brien N, Cummins E. 2010. Ranking initial environmental and human health risk resulting from environmentally relevant nanomaterials. *Journal of Environmental Science and Health Part A*. 45:992-1007.

Obbard RW, Sadri S, Wong YQ, Khitun AA, Baker I, Thompson RC. 2014. Global warming releases microplastic legacy frozen in Arctic Sea ice. *Earth's Future*. 2:1-6.

Pauly JL, Stegmeier SJ, Allaart HA, Cheney RT, Zhang PJ, Mayer AG, et al. 1998. Inhaled cellulosic and plastic fibers found in human lung tissue. *Cancer Epidemiology, Biomarkers & Prevention*. 7:419-428.

Ribic CA. 1998. Use of indicator items to monitor marine debris on a New Jersey beach from 1991 to 1996. *Marine Pollution Bulletin*. 36:887-891.

Rillig MC. 2012. Microplastic in terrestrial ecosystems and the soil? *Environmental Science & Technology*. 46:6453-6454.

Rocha-Santos T, Duarte AC. 2015. A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment. *Trends in Analytical Chemistry*. 65:47-53.

Rochman CM, Hoh E, Kurobe T, Teh SJ. 2013. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. *Scientific Reports*. 3:3263.

Rochman CM, Hentschel BT, Teh SJ. 2014. Long-term sorption of metals is similar among plastic types: Implications for plastic debris in aquatic environments. *PloS One*. 9:e85433.

Rochman CM. 2015. The complex mixture, fate and toxicity of chemicals associated with plastic debris in the marine environment. In M. Bergmann, L. Gutow & M. Klages (eds.), *Marine Anthropogenic Litter* (pp. 117-140). Springer: Berlin.

Seltenrich N. 2015. New link in the food chain? Marine plastic pollution and seafood safety. *Environmental Health Perspectives*. 123:A34-41.

Syberg K, Khan FR, Selck H, Palmqvist A, Banta GT, Daley J, et al. 2015. Microplastics: Addressing ecological risk through lessons learned. *Environmental Toxicology and Chemistry*. 34:945-953.

Tang WJ, Fernandez JG, Sohn JJ, Amemiya CT. 2015. Chitin is endogenously produced in vertebrates. *Current Biology*. 25:897-900.

United States Environmental Protection Agency (USEPA). 2015. Summary of expert discussion forum on possible human health risks from microplastics in the marine environment. EPA Forum Convened on April 23, 2014. Washington, DC: Marine Pollution Control Branch, Office of Wetlands, Oceans and Watersheds, U.S. Environmental Protection Agency (6 February 2015). Available at: http://www2.epa.gov/sites/production/files/2015-02/documents/trash_free_waters_microplastics_expert_forum_meeting_summary_2-6-15.pdf. Accessed February 17, 2015.

Van Cauwenberghe L, Janssen CR. 2014. Microplastics in bivalves cultured for human consumption. *Environmental Pollution*. 193:65-70.

Verschoor A, Herremans J, Peijnenburg W, Peters R. 2015. Size and amount of microplastics in toothpastes. National Institute for Public health and the Environment Ministry of Health, Welfare and Sport, The Netherlands. Available at: http://www.beatthemicrobead.org/images/pdf/andere_pdfs/007514_Microplastics_poster_V1-2.pdf. Accessed June 11, 2015.

Watts AJ, Lewis C, Goodhead RM, Beckett SJ, Moger J, Tyler CR, et al. 2014. Uptake and retention of microplastics by the shore crab *Carcinus maenas*. *Environmental Science & Technology*. 48:8823-8830.

Wright SL, Thompson RC, Galloway TS. 2013. The physical impacts of microplastics on marine organisms: a review. *Environmental Pollution*. 178:483-492.

Yang D, Shi H, Li L, Li J, Jabeen K, Kolandhasamy P. 2015. Microplastic pollution in table salts from China. *Environmental Science & Technology*. 49:13622-7.

Yonkos LT, Friedel EA, Perez-Reyes AC, Ghosal S, Arthur CD. 2014. Microplastics in four estuarine rivers in the Chesapeake Bay, U.S.A. *Environmental Science & Technology*. 48:14195-202.

Zettler ER, Mincer TJ, Amaral-Zettler LA. 2013. Life in the "Plastisphere": microbial communities on plastic marine debris. *Environmental Science & Technology*. 47:7137-7146.

Zubris KA, Richards BK. 2005. Synthetic fibers as an indicator of land application of sludge. *Environmental Pollution*. 138:201-211.