The Environmental Impacts of Microplastics:
An Investigation of Microplastic Pollution in North Country Waterbodies

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Image: Grasse River, Canton, New York

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EXECUTIVE SUMMARY

Freshwater is one of the most important and one of the scarcest resources that exists on this planet. It is home to a set of unique organisms and is an essential requirement for much of life. Humans rely on freshwater ecosystems for numerous ecosystem services, and, as a whole, the freshwater ecosystems on earth play an important role in the maintenance and function of the planet. Despite freshwater being one of the most important resources, it is also unfortunately one of the most abused resources on our planet. Throughout human existence water has faced a continuous threat of pollution, and while the threat of pollution has remained constant, the types of pollution have evolved and expanded over time. Currently, freshwater ecosystems across the planet are being threatened by a new form of pollution—microplastic pollution.

Microplastics, which are plastic particles or fibers smaller than 5 millimeters (mm) in size, are one of the many environmentally-detrimental outcomes of modern society's widespread use of plastics. Derived from petroleum, microplastics are common additives to personal care and cosmetic products (PCCPs) and are also produced from the use of synthetic fibers in textiles. Microplastics can also be produced from degradation and breakdown of macroplastic debris, which commonly accumulates in aquatic environments due to improper waste disposal. Due to their miniscule size, microplastics are not able to be removed by wastewater treatment plants, leading to their release into the environment via effluent discharge or land application of sewage sludge. Because microplastics are derived from petroleum, they are not biodegradable, which means that they persist in the ecosystems in which they are introduced.

Microplastic pollution of freshwater ecosystems poses a direct and serious threat to biodiversity. Direct impacts are exerted on aquatic organisms that ingest microplastics, and indirect impacts are exerted from the role that microplastics play in alteration of habitat structure, bioaccumulation and biomagnification of toxins adsorbed and carried by microplastics, and endangerment of ecosystem functions and services. Through adverse effects on individual species and populations, the impacts of microplastic pollution act to threaten species survival, community structure, and ecosystem function, making this a global conservation issue.

We sought to investigate the issue of microplastic pollution in North Country waterbodies framing our investigation as a conservation issue. Microplastic pollution has been found in North Country waterbodies including the Great Lakes, the St. Lawrence River, and Lake Champlain. Our research reveals the sources of microplastic pollution, the threat that microplastic pollution poses to biodiversity, the extent of microplastic pollution in the North Country, the various stakeholders who have an interest in the issue of microplastic pollution, the governmental issues that relate to the topic, and potential solutions to this widespread and prevalent pollution problem. Based on our findings we conclude that in order to adequately address and remedy the issue of microplastic pollution in North Country waterbodies, immediate action is needed in the form of consumer education and legislation to target and eliminate the sources of microplastic pollution in a timely manner. In order to be effective, an adequate solution needs to be inexpensive, require minimal changes to lifestyle, be ubiquitous and global in its application, and offer an effective strategy both for preventing continued pollution of waterways and for removing the microplastics that are already present.

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INTRODUCTION

The following document offers an in-depth overview and analysis of the issue of microplastic pollution of North Country waterbodies. It frames microplastic pollution in the context of the threat it poses to biodiversity by its direct and indirect effects on freshwater ecosystems. Within this document, we detail the methodology of our investigation which consisted of research, interviews, a market inventory of face wash sold in the North Country, and a microplastics survey issued to North Country residents. We also examine the multiple sources of microplastic pollution including PCCPs, synthetic textiles, land application of sewage sludge (the solid waste that is generated/collected from the wastewater treatment process), and degradation of larger plastic debris. We further identify the many relevant parties who hold a stake in the issue of microplastic pollution, including North Country residents, environmental organizations, scientists and researchers, government officials and politicians, as well as the environment itself and the numerous species and processes that stand to be impacted by microplastic contamination of waterbodies. We provide an overview and analysis of relevant legislation and government action regarding microplastic pollution not only in the North Country, but throughout the United States and the rest of the world as well. Finally, we identify and evaluate potential solutions to the issue of microplastic contamination of North Country waterways, ultimately suggesting a best solution and an accompanying step-by-step plan by which to implement said solution.

METHODS

In order to conduct our case study, we used a variety of resources and strategies to assess the current state of microplastic pollution in North Country waterbodies. Additionally, we assessed public perception, awareness, and concern of the issue as well as current and future solutions to the issue. We conducted an inventory of the PCCPs available at four major North Country retailers, designed and implemented a survey, and used Geographic Information Systems (GIS) to generate relevant maps. We also conducted phone and email interviews and looked at primary scientific journal articles as well as secondary sources such as newspaper articles and government documents.

Research

One of the primary forms of research for our project entailed finding and reading sources that discussed or were related to the topic of microplastic pollution in aquatic environments. Our research included reading recent news articles/radio pieces that discussed the issue of microplastic pollution, government documents related to microplastic legislation, and primary and secondary literature about scientific studies and research conducted on the topic of microplastic pollution in aquatic environments. The primary and secondary literature that we read included research on macroplastic (plastic larger than 5 mm in size) pollution in marine environments, microplastic pollution in marine environments, research on microplastics in freshwater environments, and North Country specific research related to microplastic pollution in the Great Lakes, the St. Lawrence River, and Lake Champlain. While we read as much North Country specific research as we could find, the majority of the research we examined was national and global research, which we were then able to apply to the North Country. We found the relevant scientific literature using St. Lawrence University library databases and by visiting the websites of pertinent stakeholders when applicable.

Market Inventory

Consumer preference is a strong factor contributing to and/or ameliorating the issue of microplastic pollution of waterways. Although plastic microbeads in rinse-off PCCPs such as body wash, face wash, and toothpaste are but one of many sources of microplastic pollution of waterways, it is an issue that has garnered a great deal of recent attention in the media and among policymakers and consumers. Plastic microbeads are commonly included as exfoliating agents in facial and body scrubs. An estimated 8 trillion microbeads enter streams and oceans each day in the United States (Schlanger 2015) and according to the European-based water pollution activist organization Plastic Soup Foundation (2016), cosmetics account for 3 to 4% of all microplastic pollution.

The number of plastic particles included in a single bottle of face or body wash is truly astounding, with one study finding approximately 360,000 plastic microbeads in a single bottle of Neutrogena Deep Clean Exfoliating Scrub (Blomberg 2015). Therefore, we were interested in sampling regional retailers to assess the availability and prevalence of microplastic-containing PCCPs. We sampled Kinney Drugs, Price Chopper, and Rite Aid in Canton, NY and the Walmart in Potsdam, NY (Appendix C). We chose these retailers due to their proximity to the St. Lawrence University campus and their prevalence throughout the North Country.

At each retailer, we inventoried all available face wash products for the presence of microbeads or natural exfoliants (Figure 1). We chose to assess the prevalence of microbeads in face washes because face wash is a PCCP that frequently includes microplastics. Specifically, we read the ingredient list of every available face wash product looking for the presence of polyethylene, polypropylene, polyethylene terephthalate, polymethyl methacrylate, or nylon, which are among the most common plastic ingredients in PCCPs according to the “Beat the Microbead App” created by the Plastic Soup Foundation (2016). This app, in theory, allows you to scan the barcode of any PCCP to see whether or not the product contains plastic. We downloaded this app and attempted to utilize it in our market survey, but the majority of the products we scanned were listed as “unknown” in the app. Instead we ended up scouring the ingredients list of each and every bottle of face wash for plastic ingredients. Additionally, we noted if the products made particular claims about exfoliating capacity or microbeads. If the product claimed to exfoliate, we noted the exfoliating agent, including any natural exfoliating agents such as oatmeal, walnut shell, and charcoal within the ingredient list. We also recorded the price and volume of each face wash. Each store took two to three hours to sample. We compiled the market survey results into a spreadsheet (Appendix C).

Figure 2. Face Wash PCCPs inventoried for presence of microplastics in North Country retailers.

Microplastics Survey

In addition to conducting a market inventory, we designed and distributed a survey to gauge public awareness and concern among North Country residents regarding the issue of microplastic contamination of waterways. We asked a series of questions to measure respondents' level of environmental concern and connectedness using the environmental concern and connectivity scales from Dutcher *et al.* (2007). Additionally, within the survey we asked respondents about their PCCP and synthetic textile purchasing patterns and preferences. We also asked about their awareness of this issue and their use of and concern for the long-term health and sustainability of North Country waterbodies. See Appendix B for a complete list of our survey questions.

We designed our survey to be brief (take less than 15 minutes to complete) and straightforward. We utilized the survey platform Qualtrics to design and build our survey. Prior to distributing our survey, we obtained the approval of the St. Lawrence University Institutional Review Board (SLU IRB) by writing a proposal that included our survey questions, sampling methodology, and the consent form that would be distributed to respondents. Once our survey had been approved by the SLU IRB (#2016-14), we distributed the survey using the North Country-focused environmental media platform Nature Up North, Facebook, the St. Lawrence University (SLU) faculty/staff e-mail ListServ, and the campus communication platform SLUWire with the goal of obtaining at least 200 responses. To incentivize people to take our survey, we offered respondents the chance to win a $50 gift certificate to their choice of Price Chopper or the SLU Brewer Bookstore. Additionally, we promised to donate $0.25 (25 cents) to Save the River—an environmental organization that works to protect the ecological integrity of the St. Lawrence River—for each completed survey we received (up to 400 completed surveys). The survey was available from March 16, 2016 until April 18, 2016, after which point we analyzed the survey data.

Our primary motive in utilizing a survey as part of our case study was to gain insight into a key stakeholder: North Country residents and the consumers of PCCPs / synthetic textiles. Secondarily, the survey offered us a platform from which to educate consumers and bring awareness to an issue that many people are currently unaware of.

Interviews

In addition to our literature research, market survey, and microplastics survey, we also held several interviews with pertinent stakeholders (Appendix A). Interviews were conducted using both phone interviews and email correspondence. Phone interviews were conducted with Nicole Duckam (Assemblywoman Michelle Schimel's Chief of Staff), Dr. Danielle Garneau (Associate Professor of Environmental Science at SUNY Plattsburgh), Bob Henninger (Chief Operator at Potsdam Sewage Treatment Plant), Brian Nutting (Water Quality Supervisor for the Development Authority of the North Country), and Stephanie Whyte (5 Gyres Ambassador for 5 Gyres Institute). Interviews carried out using email correspondence were conducted with U.S. Senator Kirsten Gillibrand, Leslie Haymon (Congresswoman Elise M. Stefanik's Legislative Assistant), Dave Powell (Chief Plant Operator at Plattsburgh Water Pollution Control Plant), and several PCCP manufacturing companies including Johnson & Johnson®, Neutrogena®, and Unilever®. These interviews helped us to gather pertinent information that was lacking from our literature review and also enabled us to better understand the perspectives of the various stakeholders invested in the issue of microplastic pollution.

Nicole Duckham, who is Assemblywoman Michelle Schimel's Chief of Staff, was selected to interview because Assemblywoman Schimel is the New York State Assembly sponsor for the New York State *Microbead-Free Waters Act*. Assemblywoman Schimel was unable to speak with us herself, but her Chief of Staff was able to answer our questions. We asked Nicole Duckham questions about this piece of state legislation. We also asked her how Assemblywoman Schimel became involved with/aware of the issue of microplastic contamination in New York State, how the recent passage of the national legislation impacts the state legislation, and if there is any state legislation in the works to address other sources of microplastic pollution beyond microbeads.

Leslie Haymon, who is Congresswoman Elise M. Stefanik's Legislative Assistant, was selected to interview because Congresswoman Stefanik was a co-sponsor of the *Microbead-Free Waters Act of 2015* (federal legislation). Congresswoman Stefanik was unable to speak with us herself, but her Legislative Assistant was able to answer our questions. We corresponded with Leslie Haymon over email and asked her questions about this piece of federal legislation. We also asked her about how Congresswoman Stefanik became involved with/aware of the issue of microplastic contamination in the U.S., if she believed the passing of the *Microbead-Free Waters Act of 2015* will be effective in resolving the issue of microplastic contamination, and if there is any state legislation in the works to address other sources of microplastic pollution beyond microbeads.

Senator Kirsten Gillibrand was selected to interview because she is the U.S. senator who introduced the *Microbeads-Free Waters Act of 2015* (federal legislation). We corresponded with Senator Gillibrand over email and asked her questions about this piece of federal legislation.

Specifically, we asked her about her general opinion on the environmental issue of microbead pollution and what the federal legislation will do to address this issue.

Dr. Danielle Garneau, Associate Professor of Environmental Science at SUNY Plattsburgh, was selected to interview because she is one of the leading researchers on microplastic pollution in North Country waterbodies. We came across her name when reading a North Country Public Radio (NCPR) segment about microplastic pollution in the North Country (Hirsch 2015). Specifically, Dr. Garneau researches microplastic pollution in Lake Champlain. We asked Dr. Garneau about her research on microplastic pollution in Lake Champlain and how she first became involved in the research. We also asked her general questions about microplastic pollution, what kind of threat this issue poses to aquatic environments, what she has discovered through her research, whether she believes the federal *Microbead Free Waters Act* will do enough to combat microplastic pollution, and if it is feasible to remove microplastics once they have entered the environment.

Bob Henninger, the Chief Operator at the Potsdam Sewage Treatment Plant, was selected to interview in order to gain the perspective of wastewater treatment plants, who are one of our main stakeholders. He was also selected because a study completed by the New York State Attorney General's Office and research conducted by Dr. Garneau and her students at SUNY Plattsburgh found microplastics present in the effluent from the Potsdam Sewage Treatment Plant, making microplastic pollution a relevant issue for this wastewater treatment plant. We spoke with Bob Henninger and asked him about the age and infrastructure of the Potsdam Sewage Treatment Plant, the capacity of the plant, the stages of treatment that the water goes through at the plant, where the effluent from the plant is discharged, what happens to the sludge that is produced at the plant, whether or not he believes it is feasible to retrofit wastewater treatment plants with the necessary means to extract microplastics from the wastewater stream, and what the greatest challenge facing wastewater treatment plants is in the coming future.

For similar reasons, Dave Powell, Chief Plant Operator at the Plattsburgh Water Pollution Control Plant (PWPCP), was selected to interview. The study completed by the New York State Attorney General's Office and research conducted by Dr. Garneau and her students at SUNY Plattsburgh found microplastics present in the effluent from the PWPCP. We corresponded with Dave Powell over email and asked him about the age and infrastructure of the PWPCP, the capacity of the PWPCP, the stages of treatment that the water goes through at the plant, where the effluent from the PWPCP is discharged, what happens to the sludge that is produced at the plant, whether or not he believes it is feasible to retrofit wastewater treatment plants with the necessary means to extract microplastics from the wastewater stream, and what the greatest challenge facing wastewater treatment plants is in the coming future.

Brian Nutting, the Water Quality Supervisor for the Development Authority of the North Country, was selected to interview because he was listed as the contact for the sludge land application facility located in Heuvelton, NY (which is one of two biosolid land application facilities for St. Lawrence County) on the permitted land application facility list on the NYSDEC website. We spoke with Brian Nutting in order to gain a better understanding about land application of sewage sludge in the North Country. We asked him about the water treatment plants from which sludge is received, the land on which sludge is applied, and whether or not anything is being done to address the presence of microplastics in sludge prior to its application on land.

We also corresponded with three major manufacturers of PCCPs: Johnson & Johnson®, Neutrogena®, and Unilever®. We wrote to these companies using internet contact forms in order to inquire into the status of their promised microplastic phase out, their timeline or plan for implementing the nationally-mandated phase out of plastic microbeads, and their justification for utilizing synthetic plastic exfoliants as opposed to natural alternatives in their products. We also asked them to clarify the scope of microplastic phase out: will the removal of microplastics from their products be enacted globally or solely within the U.S.? We received no response from Unilever®. Johnson & Johnson® replied explaining that they are unable to respond to individual questions from students due to the high volume of requests they receive, directing us instead to their website where we were able to find very little regarding their commitment and plan to phase out microplastics from their PCCPs. Likewise, Neutrogena®—which we contacted due to the high number of microplastic-containing Neutrogena PCCPs found during our market inventory—whose parent company is Johnson & Johnson®, replied with the same message as Johnson & Johnson®, but also added that they do not provide proprietary information on manufacturing, advertising, market share, competition, pricing, or strategic planning / sales information by operating unit, geographic area, or product category.

Lastly, we spoke with Stephanie Whyte, a 5 Gyres Ambassador for 5 Gyres Institute. We spoke with Stephanie Whyte because she was the representative from 5 Gyres Institute who responded to our request to learn more about 5 Gyres Institute and what they do. 5 Gyres Institute is one of the major NGOs/environmental groups working at the national level in the U.S. to raise awareness and action related to the issue of marine plastic pollution. We asked Stephanie Whyte questions about the work 5 Gyres is doing, the threat posed by microbead pollution, whether or not she believes the federal *Microbead Free Waters Act* will be effective in resolving the issue of microplastic contamination in aquatic environments, the role of macroplastics as an additional source of microplastics, what the most viable solutions are to combat the issue of plastic pollution, and what she believes is the greatest challenge standing in the way of achieving 5 Gyres' goal of plastic-free oceans.

GIS

Our methodology also included GIS spatial analysis conducted using ArcGIS 10.3.1 and data sourced from the St. Lawrence University GIS Department. Spatial analysis was used to examine North County hydrology and population density. Our spatial analysis was used to create a map showing the North Country waterbodies in which microplastic pollution has been confirmed. This includes the Great Lakes, the St. Lawrence River, and Lake Champlain (Figure 2).

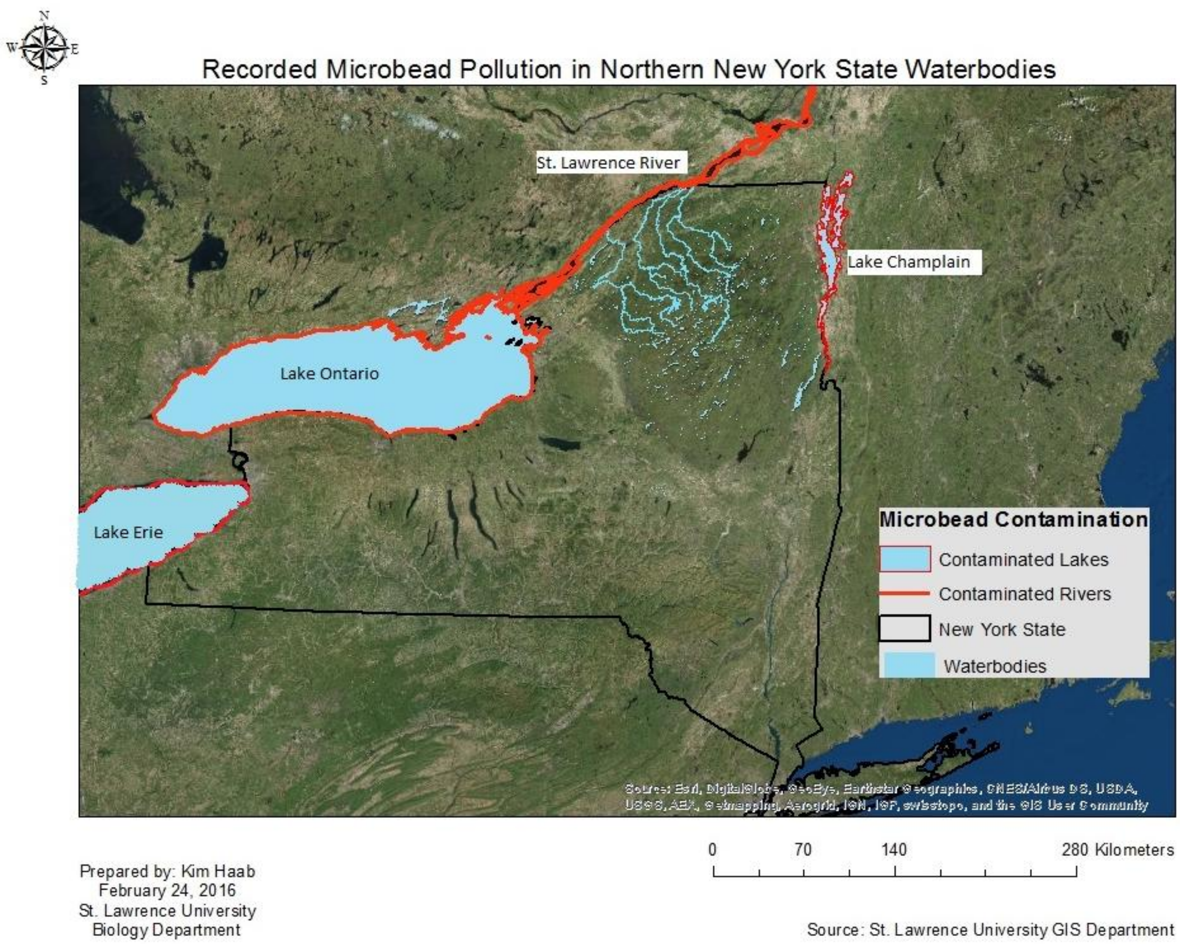

Figure 2. Map of New York waterbodies known to be contaminated with microplastic as of 2016.

PROBLEM DEFINITION

Introduction

Microplastics are small particles or fragments of plastic debris ranging in size from microns to several millimeters in diameter (Thompson 2015). The generally accepted definition of microplastics defines a minimum diameter of 0.1 micrometer (μm) (Environment Canada 2015) and a maximum diameter of 5 mm (UNEP 2015), although size delimitations and definitions vary among different research and legislation. Microplastic particles also vary in shape and may appear spherical or as elongated fibers (Thompson 2015). Particle densities vary depending on the type of polymer and any additives comprising the particle (Environment Canada 2015).

Microplastics enter our waterways through multiple sources including the degradation of larger plastic debris such as plastic bags and bottles (Seltenrich 2015), the washing of synthetic clothing and textiles (ASC Worldwide Microplastics Project 2015), microbeads from PCCPs via wastewater effluent (Seltenrich 2015; Blomberg 2015; Plastic Soup Foundation 2016; UNEP 2015), and in runoff from land application of sewage sludge contaminated with microplastics (Eriksen *et al.* 2013; Schlanger 2015). Microplastics have been reported in every major open ocean and in many freshwater lakes and rivers, thus situating the issue of microplastic contamination of aquatic ecosystems as a global conservation issue (Wright *et al.* 2013). Several studies have found microbead contamination in North Country waterbodies including the St. Lawrence River (Castañeda *et al.* 2014), Lake Champlain (Hirsch 2015; Garneau 2016), and the Great Lakes (Eriksen *et al.* 2013; Blomberg 2015).

Microplastics do not biodegrade and will therefore persist in the environments in which they are introduced. Microplastic pollution has wide-reaching immediate and long-term impacts to the health of species and ecosystems, and consequently threatens numerous services and resources on which humans and other species rely. Furthermore, as novel material in aquatic environments, the full extent of the effects microplastics may exert is unknown (Zettler *et al.* 2013). The contamination of waterways by microplastics is a direct threat to biodiversity in that there are immediate and long-term impacts to ecosystems and the organisms that inhabit them. In terms of direct impacts, microplastics can be ingested by a variety of aquatic organisms, which can lead to adverse biological effects, in turn impacting the fitness and functionality of affected species (Herzke *et al.* 2016). Microplastics also have the potential to adsorb (adhere to the outside of) and transport toxic organic contaminants from water and sediments to aquatic organisms that ingest or contact the microplastics (Herzke *et al.* 2016; Teuten *et al.* 2009; Seltenrich 2015). This can lead to bioaccumulation and biomagnification of toxins throughout ecosystem trophic levels, including trophic transfer to humans (Seltenrich 2015). In the long-term, ingestion of microplastics and accumulation of toxins have the potential to negatively impact ecosystems by decreasing wildlife diversity and overall ecosystem health, which may have long-term ramifications on commercial fisheries, tourism, and recreation.

Globally, all freshwater ecosystems, including lakes, streams, and rivers, are at risk from microplastic pollution, including North Country waterbodies. The North Country, which includes northern New York, Vermont, and southeastern Canada, has a myriad of freshwater waterbodies, many of which are currently being threatened by microplastic pollution. New York State alone has a total water area of 7,429 square miles, with water accounting for 13.6% of the state's total area (Perlman 2015). Furthermore, New York State has 70,000 miles of rivers and streams as well as over 7,600 freshwater lakes, ponds, and reservoirs, including portions of two of the five Great Lakes (NYSDEC 2016b). Thus far, microplastic pollution has been documented in major freshwater waterbodies in New York State including the St. Lawrence River (Castañeda *et al.* 2014), Lake Champlain (Hirsch 2015), and the New York portions of Lake Ontario and Lake Erie (Eriksen *et al.* 2013). Microplastic pollution poses a direct threat to the biodiversity and functionality of North Country waterbodies, which endangers the instrumental value associated with healthy waterways as well as the intrinsic value held by many North Country residents and tourists who utilize waterbodies in the region.

National legislation exists prohibiting the inclusion of plastic microbeads in PCCPs beginning in 2017, but additional public policy, international agreements, and consumer education and awareness are needed in order to effectively combat and remediate the many forms, sources, and negative impacts of microplastic contamination in regional and global waterways.

The issue of microplastic contamination of North Country waterways affects numerous stakeholders including the manufacturers and distributors of plastic and plastic containing-products (including synthetic textiles and PCCPs), the consumers of such products, as well as politicians, government officials, and government organizations working to implement, enforce, and regulate legislation to combat the impacts of microplastic pollution. Governments, politicians, and government organizations at the local, state, and federal level all have a stake in this issue. Furthermore, non-governmental organizations (NGOs) and environmental groups operating at the local, state, and national level to raise awareness and combat microplastic pollution are also key stakeholders. Additionally, local residents and visitors who utilize North Country waterways and waterbodies for recreational and commercial purposes have a large stake in the issue at hand. There are many scientists, researchers, and environmental groups working to assess, understand, and begin to combat microplastic contamination of North Country waterways—and, more broadly, of waterways all over the world. Wastewater treatment facilities, sludge applicators, and landowners on whose land microplastic-contaminated sludge is being applied also play an important role in this issue as one of the federally and nationally regulated major sources of microplastic contamination of our waterways. Lastly, the health, sustainability, and longevity of our marine and freshwater environments is at stake, threatening to impact not only the many species of plants and animals that rely on this habitat, but also the countless humans that rely—whether consciously or unconsciously— on the services provided by these ecosystems.

Background and History

Plastics—synthetic organic compounds that consist of repeating units of monomers—are one of the most widely used materials in the world, with near ubiquitous application in our lives today. Used as far back as 1600 B.C. by ancient Mesoamericans to create figurines and bands, plastic has undergone a series of innovations and alterations over time, culminating a seemingly infinite array of uses and applications. Consequently, the global production of plastics has increased steadily throughout history, reaching a staggering 265 million tons in 2010 (Figure 3). Plastics are light, cheap, and durable, making them widely used in a diversity of products. However, the cheap costs of plastics also allow them to be used only once before being disposed of, resulting in the generation of mass amounts of litter. This plastic litter ranges in size from macrodebris (such as plastic chairs and shoes) to microdebris (plastic fragments less than 5 mm in diameter) which accumulates in landfills, rivers, and oceans all over the world (Hammer *et al.* 2012).

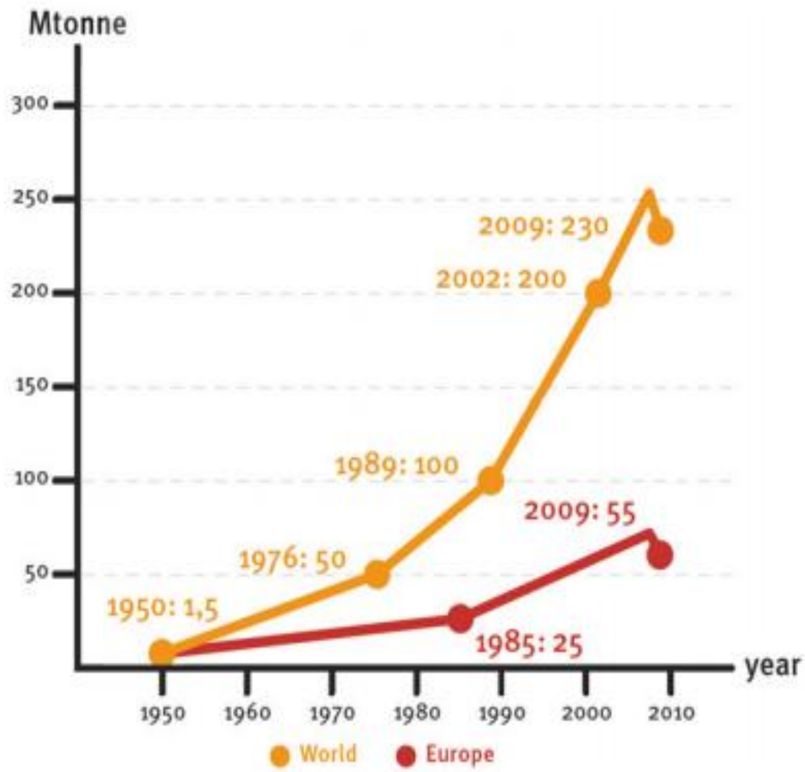

Figure 3. World plastics production from 1950 to 2009 in millions of tons. From Hammer *et al.* 2012.

The term microplastic first came into popular use in 2004, when researchers began reporting on the accumulation of microscopic pieces of plastic in marine habitats (Thompson 2015). Microplastic pollution of marine and freshwater environments originates from improper waste management by commercial, recreational, and military vessels, land-based plastics blown in by the wind, and from untreated wastewater effluent contaminated with microplastic fibers and beads. Larger plastic debris subsequently breaks down upon entering marine and freshwater environments primarily through photo-oxidative degradation, resulting in an additional influx of microplastic pollution into the environment (Hammer *et al.* 2012).

Over the past decade there has been increasing interest in the topic of microplastic contamination among scientists, with over 100 publications on microplastics to date, along with increased interest from the media, policymakers, and the general public (Thompson 2015). However, the majority of research regarding microplastic pollution has been focused on marine environments. Microplastic pollution has only recently been documented within the surface waters and sediments of freshwater environments (Castañeda *et al.* 2014). Recent legislation addresses some sources of microplastic pollution, but in general fails to adequately protect waterways from the numerous sources and impacts of microplastic contamination in a timely manner.

Threats to Biodiversity

Overview

The contamination of waterways by microplastics results in pollution that is a direct threat to biodiversity through immediate and long-term impacts to ecosystems and the organisms that inhabit them. Direct impacts result from ingestion of microplastics by both marine and freshwater organisms. Microplastic ingestion has been shown to have adverse biological effects on aquatic organisms, which can reduce the fitness and functionality of these organisms. Many of the freshwater organisms impacted by microplastic pollution inhabit North Country waterbodies. This includes important freshwater organisms such as zooplankton, aquatic worms, crayfish, native mussels, crabs, and several fish species including the yellow perch (Figure 4). This list highlights several examples of North Country wildlife that are being negatively impacted by microplastic pollution, however, more research is needed before a full assessment of the impact of microplastic pollution on freshwater species in the North Country can be made. For many of these organisms, ingested microplastics accumulate in the gastrointestinal tract, which creates a sense of false satiation leading to reduced energy acquisition via reduced feeding effort (Castañeda *et al.* 2014). The impacts of microplastic pollution have been felt by aquatic organisms at every trophic level. Every organism plays an ecological role that is necessary to maintain the health, functionality, and resiliency of an ecosystem. Loss or impairment of an organism's role can lead to adverse population and ecosystem scale impacts.

Figure 4. North Country freshwater organisms negatively impacted by microplastic pollution. A- Zooplankton (*Daphnia pulex*) B- Aquatic earthworm (*Oligochaeta*) C- Crayfish (*Decapoda*) D- Rainbow mussel (*Villosa iris*) E- Atlantic blue crab (*Callinectes sapidus*) F- Yellow perch (*Perca flavescens*).

In addition to this direct impact, microplastic pollution also leads to several indirect impacts on aquatic environments. Such impacts include contamination of sediments with microplastics (Carson *et al.* 2011), the transfer and biomagnification of microplastics throughout food webs, the transfer and biomagnification of toxins carried and adsorbed by microplastics (Herzke *et al.* 2016; Teuten *et al.* 2009; Seltenrich 2015), and an increased risk for exotic species establishment and pathogen proliferation as microplastics act as vectors for both exotic species and pathogens (Wagner *et al.* 2014). Furthermore, microplastics have the potential to provide novel ecological habitats for microbial communities, which can lead to changes in community structure (Zettler *et al.* 2013). These indirect effects have the potential to disrupt normal ecosystem functions, which poses a direct threat to the ecosystem services provided by aquatic organisms and aquatic environments. Together, the direct and indirect impacts of microplastic pollution threaten the biodiversity of aquatic environments and threaten to disrupt important ecosystem services. Since microplastics do not biodegrade, these impacts will be felt long-term. Ultimately, microplastic pollution is a global conservation issue due to its long-lasting and ubiquitous nature (Wright *et al.* 2013b).

Direct Impacts—Ingestion of Microplastic

In terms of direct impacts, microplastics can be ingested by a variety of aquatic organisms, which can lead to varied biological effects. Organisms at all trophic levels have felt the impacts of microplastic pollution. Many microplastics that enter aquatic environments settle and contaminate the bottom sediments of waterbodies. This poses a risk to benthic (bottom-dwelling) organisms as well as to aquatic organisms that utilize sediments at any point in their life cycle. Benthic invertebrates that have been shown to ingest microplastics include burrowing bivalves, crayfish, and aquatic worms (Covich *et al.* 1999). A study of the marine lugworm *Arenicola marina* revealed that lugworms directly ingest microplastics from the sediments that they inhabit. While this study could determine no significant adverse effect from microplastic ingestion on the overall energy budget of lugworms, researchers did find potential for long-term impacts on the lugworms due to the transfer of adsorbed contaminants within/on the ingested microplastics (Cauwenberghe *et al.* 2015). The detrimental transfer of pollutants and harmful chemicals from ingested microplastics to the gut tissues of aquatic worms has been confirmed by other studies. Pollutants and chemical additives are transferred from microplastics to the gut tissues of worms when ingested, leading to a reduced ability for worms to remove pathogenic bacteria, diminished ability of worms to engineer sediments through the process of bioturbation, increased susceptibility to oxidative stress, and increased worm mortality. Thus, microplastics and the toxins they carry are having direct adverse impacts on aquatic worms (Browne *et al.* 2013).

Many aquatic worms, including lugworms, are important bioengineers in the ecosystems they inhabit because of their role as bioturbators, which means that they move and alter the composition of sediments. By altering the ability of these worms to function and survive, entire ecosystems are put at risk (Browne *et al.* 2013). Another study on deposit-feeding marine worms found that consistent exposure to sediments contaminated with microplastics led to reduced feeding activity, longer gut residency time of ingested materials, and inflammation, all of which led to an overall depletion of the worms' energy reserves by 50% (Wright *et al.* 2013a). Aquatic worms are keystone species in the ecosystems they inhabit because of their important role as bioturbators, by which they irrigate sediments. Aquatic worms are also an important source of prey for fish and wading birds, and a decrease in worm abundance could have significant impacts on the species that rely on them for food. Furthermore, when worms contaminated with microplastics are consumed by other species, there is potential for bioaccumulation and biomagnification of the microplastics as well as the toxins that the microplastics carry (Wright *et al.* 2013a).

The aforementioned impacts of microplastics on benthic invertebrates have been confirmed for numerous marine benthic species, due in part to the fact that microplastic pollution has been better studied in marine environments than in freshwater environments. However, it stands to reason that freshwater benthic organisms experiencing microplastic pollution would be impacted in similar ways as their marine equivalents. Burrowing bivalves play an important functional role in freshwater ecosystems (Vaughn and Hakenkamp 2001). These organisms, such as clams, oysters, cockles, mussels, and scallops, live and feed in the sediments as filter feeders. Their functional roles in aquatic ecosystems include filtration of phytoplankton, bacteria, and particulate organic matter from the water column, maintenance of proper nutrient dynamics through excretion and bio-deposition of feces, provision of habitat for epiphytic and epizoic organisms that use the shells of bivalves as substrates, and bioturbation of sediments, which releases nutrients from the sediments to the water column (Vaughn and Hakenkamp 2001).

Their role as filter feeders, which helps maintain overall ecosystem health through water filtration, makes them particularly vulnerable to ingesting microplastics in aquatic environments that have been contaminated with microplastics. There has been an alarming decline in native burrowing bivalves in lakes and rivers globally, exacerbated by the invasion of exotic burrowing bivalves (Vaughn and Hakenkamp 2001). The direct ingestion of microplastics will further exacerbate the decline of native freshwater bivalve species, which will severely impact ecosystem health and functionality due to the loss of the important functional roles carried out by native burrowing bivalves. As another example, microplastic pollution has been shown to impact marine mussels, such as *Mytilus edulis*, because as filter feeders mussels are susceptible to ingesting microplastics. Mussels ingest microplastics when filtering contaminated water, and although there is no significant adverse effect from microplastic ingestion on the overall energy budget of mussels, there is the potential for long-term impacts due to the transfer of adsorbed contaminants within/on the ingested microplastics (Cauwenberghe et al 2015).

Small filter-feeding organisms are not the only filter feeders at risk from microplastic pollution. For example, humpback whales (*Megaptera novaeangliae*) as marine macro filter-feeders also accumulate microplastics from contaminated water, shown by the fact that microplastics have been found in the intestines of humpback whales (Besseling *et al.* 2015). Microplastics pose a significant risk to aquatic organisms that filter/ingest water indiscriminately, such as the humpback whale, which can consume up to 10,000 gallons of water at one time while filter-feeding for krill, plankton, and small fish (Bean-Mellinger 2016). The direct biological effects of ingested microplastics are not known for humpback whales, although the transfer of toxins from the microplastics into the tissues of whales is of particular concern. Whales perform several functions that are essential for maintaining healthy and functional ecosystems, including recycling of nutrients and enhancing productivity in feeding areas (Brown 2014). Loss of whales, or a decline in their ability to survive and function, would threaten the important ecosystem services provided by whales, which in turn could lead to changes in the community structure of marine environments. While whales do not inhabit freshwater environments, the accumulation of microplastics within whale intestines via direct ingestion shows that organisms of all sizes can be impacted by microplastic pollution.

Another marine benthic organism that has been negatively impacted by microplastic pollution is the Norway lobster (*Nephrops norvegicus*). As bottom feeders living in the benthos, lobsters have a high risk of contacting and consuming microplastics that have settled into sediments. In coastal marine environments, microplastic contamination was found in 83% of sampled lobsters, with plastic fibers/filaments being the most prevalent form of microplastic. Further experimentation on the lobsters revealed that lobsters that consumed fish laced with strands of polypropylene rope ingested, but did not excrete, the plastic strands, further supporting the notion that microplastics are internally accumulated by the lobsters (Murray and Cowie 2011). A high prevalence of plastics in Norway lobsters may have implications for the health of the stock, which could have detrimental impacts on commercially-important Norway lobster fisheries, particularly in Europe where the Norway lobster is one of the most important commercial crustaceans. In addition to the impact microplastic pollution could have on commercial lobster operations, further ecosystem impacts could result due to the important role fulfilled by lobsters as benthic predators. Alteration of the structure of benthic communities from a decline in lobster abundance would likely result in a trophic cascade and the subsequent alteration of community structure, in turn leading to an alteration in community function (Murray and Cowie 2011).

In addition to the Norway lobster, the negative effects of microplastics have been shown in other crustaceans, such as the shore crab *Carcinus maenas*. Watts *et al.* (2014) found that in addition to ingestion, microplastics can also be taken up by aquatic organisms via respiration. The researchers colored microspheres and other plastics with fluorescent dye, traced the plastics, and found the microplastics retained in the foregut and on the external surface of gills of the shore crabs. In this way, the researchers showed the potential for microplastic contamination to move up marine ecosystems through the food chain (the crabs ate mussels which were contaminated with microplastics) as well as via ventilation. Freshwater crustaceans will likely be impacted in similar ways as marine crustaceans by microplastic pollution.

Bottom-dwelling fish species (demersal fishes) face similar risks and impacts from microplastic pollution, as do other bottom-dwelling organisms. Lusher *et al.* (2013) studied demersal fish species in the English Channel and found plastic in the gastrointestinal tracts of 36.5% of sampled fish, including five different demersal fish species. Ingestion of microplastics can have adverse impacts on fish biology, including physical and chemical effects such as stimulation of a false sense of satiation, which leads to decreased food consumption, diminished energy reserves, and clogging of digestive systems. Microplastic ingestion can also lead to the transfer of toxins from ingested microplastics to the fish tissues, which can act as endocrine disruptors and impact reproductive output. There is also the potential for trophic transfer and biomagnification of toxins to higher trophic levels (Lusher *et al.* 2013). A wide range of fish species, beyond just demersal species, have been shown to ingest microplastics. Lusher *et al.* (2013) also sampled five pelagic fish species (species that live in the open-water zone of oceans or lakes) and again found plastic in the gastrointestinal tracts of all five species. Hence, microplastic ingestion appears to be common across a range of fish species irrespective of feeding habitat (Lusher *et al.* 2013). Microplastics have also been found in the guts of yellow perch (*Perca flavescens*) living in Lake Champlain, showing that North Country fishes are also threatened by microplastic pollution (Hirsch 2015).

The threat that microplastics pose to fish species at all trophic levels often draws attention because of the consequences such an impact could have on commercially-exploited fish species. While this certainly is a valid concern, the loss of fish species would also have serious ecological consequences in addition to serious economic consequences. When fish species are threatened, so too are the ecosystem services provided by fish. This in turn leads to adverse consequences for biodiversity, ecosystem function, and human welfare. In both marine and freshwater environments, fish provide a number of invaluable ecosystem services including regulation of aquatic food webs, recycling of nutrients, regulation of ecosystem resilience, redistribution of bottom substrates, regulation of carbon fluxes from water to the atmosphere, maintenance of sediment processes, maintenance of genetic, species, and ecosystem diversity, linkage within aquatic ecosystems, linkage between aquatic and terrestrial ecosystems, transport of carbon, nutrients, and minerals, and transport of energy. Fish are also an important and valuable food source for humans, especially as a protein source for many human populations (Holmlund and Hammer 1999). When fish species are lost, the ecosystem services they provide will also be lost.

The impacts of microplastic pollution are also felt by terrestrial organisms, such as birds, which rely on aquatic ecosystems for food. The impacts of microplastic pollution on seabirds has been well researched (Colabuono *et al.* 2009; Foster *et al.* 2011; Herzke *et al.* 2016), and these findings can be applied to waterfowl that occupy similar trophic levels in freshwater ecosystems. Seabirds, which inhabit coastal and marine habitats, rely heavily on fish as a source of food. When fish contaminated with microplastics are consumed, these microplastics can be transferred and bioaccumulated within the gastrointestinal tracts and tissues of seabirds. Colabuono *et al.* (2009) studied the effects of plastic pollution on *Procellariiformes*, an order of seabirds that includes albatrosses, petrels and shearwaters, storm petrels, and diving petrels. Analysis of the stomachs and intestines of dead birds collected along the coast of Brazil revealed that plastic fragments and pellets were the most frequent items found in the digestive tracts of eight different species of *Procellariiformes*. Plastic ingestion by seabirds negatively affects the feeding efficiency of the birds, thus threatening their ability to survive and reproduce. Birds are often important predators in aquatic environments, and altering the density of bird populations could disrupt aquatic community structure and result in a top-down trophic cascade (Colabuono *et al.* 2009).

Study of another common seabird, the Northern Fulmar (*Fulmarus glacialis*), revealed that persistent organic pollutants found in the tissues of Northern Fulmars came primarily from the tissues of the prey they consumed (Herzke *et al.* 2016). Microplastics act as a vector for toxins, and when consumed by fish these toxins can accumulate in fish tissues. The toxins can then be transferred and biomagnified to top-predators that consume contaminated fish, such as Northern Fulmars. Further study of Northern Fulmars also revealed that toxins such as PCBs, pesticides, and other persistent organic pollutants can be further biomagnified in tissues of Northern Fulmar predators such as the arctic fox. Thus, entire food webs that span aquatic and terrestrial ecosystems, both within the North Country and elsewhere, can be adversely affected by microplastic pollution (Foster *et al.* 2011).

Most concerning of all, perhaps, is the impact that microplastic ingestion has on zooplankton. Zooplankton are an ecologically important group of aquatic heterotrophs and are one of the most ubiquitous organisms in aquatic ecosystems worldwide. Zooplankton consume phytoplankton and act as a food source for higher trophic level aquatic organisms, forming a key energetic link between the primary producers and higher trophic organisms. Furthermore, zooplankton also play an important ecological role in aquatic nutrient cycling through consuming, and then repackaging particulate organic matter in the water. The particulate organic matter consumed by zooplankton is repackaged in the form of fecal pellets, which sink once excreted, acting to spread nutrients and particulate organic matter to other strata of aquatic ecosystems, including the benthos (Cole *et al.* 2016). Zooplankton frequently consume microplastics smaller than one millimeter in size when living in aquatic environments that have been contaminated with microplastics. Many of the ingested microplastic particles are excreted in the zooplankton feces, and the presence of microplastics in the feces significantly reduces the density of the fecal pellets, which decreases the sinking rate of the pellets. Zooplankton feces are an important food source for aquatic organisms and contribute to the aquatic vertical flux of particulate organic matter and nutrients. Thus, when present at high concentrations, microplastics are threatening the important ecological role played by zooplankton feces. Additionally, organisms that utilize zooplankton fecal pellets for food run the risk of accumulating microplastics from the fecal pellets upon consumption (Cole *et al.* 2016). Although zooplankton have been studied primarily in marine environments, they are equally important organisms in freshwater environments, making this concern applicable to microplastic contamination in freshwater.

In addition to the aforementioned species, Dr. Danielle Garneau, an associate professor of environmental science at SUNY Plattsburgh whose research focuses on microplastics in Lake Champlain, confirmed finding evidence of microplastic ingestion and contamination in yellow-perch, bass, sunfish, rainbow smelt, sculpin, and various arthropod species (Garneau, personal communication[1]). Across the globe, researchers have confirmed the California blackworm (*Lumbriculus variegatus*), *Daphnia magna*—a freshwater flea—New Zealand mud snail (*Potamopyrgus antipodarum*), as well as three species of amphipod crustacean (*Gammarus pulex*, *Notodromas monacha*, and *Hyalella azteca*) to be among the numerous freshwater organisms that are impacted by microplastic pollution (Environment Canada 2015).

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[1] Phone Interview 29 February 2016

Overall, microplastic pollution directly affects a wide range of aquatic organisms, and these adverse impacts are felt at all trophic levels. Microplastics have been found within a wide range of species, ranging from zooplankton and benthic invertebrates to fish and predatory birds. While many aquatic organisms accumulate microplastics from direct ingestion, others bioaccumulate microplastics through trophic transfer from lower trophic levels. Microplastics exert a wide range of adverse effects on aquatic organisms, including impacts such as inducement of satiation, decreased feeding efficiency, inflammation, alteration of fecal density, increased mortality, and long-term effects due to the transfer of toxins from the microplastics to organismal tissues (Teuten *et al.* 2009). Many of these effects threaten the abilities of impacted species to survive, function, and reproduce. When the survival and functionality of a species is threatened, the community structure of aquatic ecosystems and the ecosystem services provided by species are also threatened. Therefore, microplastic pollution, due to the direct adverse impacts that arise from ingestion and transfer of microplastics within aquatic organisms, poses a serious threat to biodiversity within the world's aquatic environments and the terrestrial organisms that rely on aquatic environments for food.

Indirect Impact—Alteration of Habitat Structure

In addition to the adverse impacts that microplastics have on aquatic organisms that directly ingest microplastics, microplastic pollution in aquatic environments can also lead to a number of consequential indirect impacts, including the alteration of habitat structure within an aquatic community. First, alteration of habitat structure can result from the contamination of sediments by microplastics, which changes the water movement and heat transfer within sediments. The presence of microplastics significantly increases the permeability of soils.

Additionally, soils containing microplastics warm more slowly and reach lower maximum temperatures than soils without microplastics (Carson *et al.* 2011). Thus, microplastics impact water movement and heat transfer within sediments, which could have significant impacts on organisms that live in sediments for all or part of their life cycle and on overall ecosystem structure and function.

In addition to the alteration of sediment structure, microplastics can further alter habitat structure by acting as novel habitat that does not naturally exist in aquatic environments. Specifically, microplastics have the potential to provide novel ecological habitats for microbial communities, which can lead to changes in community structure in aquatic environments (Zettler *et al.*2013). A diverse microbial community of heterotrophs, autotrophs, predators, and symbionts have been found living on marine plastic debris. A plastic-based habitat is a unique habitat because plastic persists for much longer than most natural floating marine substrates. Plastics also have a hydrophobic surface that promotes microbial colonization and biofilm formation (Zettler *et al.* 2013). This results in plastic-based communities that are distinct from surrounding surface water, implying that plastic serves as a novel ecological habitat in aquatic ecosystems. Thus, the presence of plastic, including microplastics, in aquatic environments creates new habitat availability for certain organisms such as microbes, which can then alter the natural/pre-existing habitats and impact overall community structure (Zettler *et al.* 2013).

The establishment of microbial communities on plastics is particularly concerning because this could promote the harboring of opportunistic pathogens, which in turn could result in serious community-scale impacts, for instance by spreading disease to other aquatic organisms (Zettler *et al.* 2013). The same can be said about the spread of exotic species since microplastics serve as vectors for pathogens as well as for exotic species. Furthermore, many of the bacteria that colonize plastics are hydrocarbon-degrading bacteria, which can result in fragmentation of macroplastics into smaller microplastics, thus acting as another microplastic source. Moreover, opportunistic human pathogens have been found on plastic particles, meaning that microplastics can directly threaten human health by acting as vectors for waterborne diseases. Given the high mobility of microplastics within water, microplastics colonized by pathogens and/or exotic species have the ability to spread easily and rapidly between aquatic ecosystems, with the potential to proliferate disease and exotic species invasions, both of which could cause significant changes to existing community structures (Wagner *et al*. 2011).

The presence of microplastics in aquatic environments provides novel habitat for other organisms besides pathogens and exotic species, such as the pelagic insect *Halobates sericeus*. Commonly known as sea skaters, this type of water strider inhabits the open sea. However, this insect requires the presence of hard substrate for egg-laying, and thus for successful reproduction. The buildup of microplastics acts to introduce a hard-substrate habitat in areas where such substrate is naturally rare, in turn allowing for the existence and proliferation of hard-substrate-requiring organisms in areas of aquatic environments where they have not been able to previously exist. Microplastics have released this pelagic insect from the substrate limitations it faces for reproduction, which has led to increased abundance of these insects and spread of these insects into areas of the open ocean where they were not previously able to exist. In this instance, microplastics alter habitat structure in a way that leads to population-level changes, which in turn have the potential to cause changes in overall community structure and thus ecosystem structure and function (Goldstein *et al.* 2012).

Indirect Impact—Bioaccumulation/Magnification of Toxins

Microplastics also exert indirect impacts on aquatic communities through their ability to adsorb and transport toxic organic contaminants to sediments and ecosystem consumers (Herzke *et al.* 2016; Teuten *et al.* 2009; Seltenrich 2015). This can lead to bioaccumulation and biomagnification of toxins throughout the trophic levels of microplastic-polluted ecosystems. As previously mentioned, organisms that directly ingest microplastics face long-term biological consequences from the transfer and accumulation of toxins from the microplastics to the tissues of the organism. The accumulation of toxins in organismal tissues enables biomagnification of the accumulated toxins throughout food webs from low to high trophic levels. Toxins and chemical contaminants are either contained by the plastic from additives used during manufacturing, or plastics adsorb contaminants encountered in the surrounding water, acting like a sponge (Teuten *et al.* 2009). Microplastics present in terrestrial soils, such as what results from land application of sewage sludge, can adsorb toxins and contaminants prior to being washed via runoff into waterbodies (Rochman *et al.* 2015). Due to this tendency, a single plastic microbead can be one million times more toxic than the water around it (5 Gyres Institute 2016). Common persistent organic pollutants (POPs) adsorbed and carried by microplastics include polycyclic aromatic hydrocarbons such as dichlorodiphenyltrichloroethane (DDT), petroleum hydrocarbons, organochlorine pesticides, alkylphenols, bisphenol A (BPA), phthalates, polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs) (Teuten *et al.* 2009; Herzke *et al.* 2016).

The small size of microplastics allows them to carry chemicals of an even smaller molecular size, which means that the chemicals are able to penetrate the cells of living animals.

Once in cells, these chemicals can interact with biologically important molecules and may disrupt endocrine systems. The biological consequences of all POPs is not known, however, many of the POPs that have been studied disrupt endocrine systems within impacted organisms. This includes exertion of oestrogenic effects, reduction of testosterone production, and malformations of reproductive organs. Not only do plastics act as vectors for the transport of POPs, but they also may increase the environmental persistence of POPs, since adsorption of contaminants to plastic inhibits the biodegradation of contaminants. For most species, plastic ingestion is the most common route of contaminant transfer, primarily in lower trophic levels. Tissue concentrations of POPs are then amplified through the food web via biomagnification in higher trophic organisms (Teuten *et al.* 2009). Thus, the transfer of toxins from plastics to aquatic organisms and the subsequent biomagnification that results has the potential to adversely impact a variety of species in the long-term, primarily through endocrine disruption. Endocrine disruption poses a direct threat to the reproduction, and thus survival, of populations and species, further highlighting how serious of a conservation issue microplastic pollution is.

Indirect Impact—Alteration of Ecosystem Function / Endangerment of Ecosystem Services

When the survival, health, functionality, and reproduction of an organism is at risk, so too is the ecological role of that organism. Communities and ecosystems are a complex interplay of a variety of species, each of which contribute in some way to the proper structure and function of that community and ecosystem. When a species is adversely impacted or threatened, so too is its ecological role and the ecosystem service(s) that result. Ecosystem services are the benefits provided to humans, both directly and indirectly, by ecosystems and biodiversity. Individual aquatic organisms and ecosystems contribute to a variety of ecosystem services, several of which have already been discussed. However, freshwater environments as a whole, when functioning properly, also provide a number of ecosystem services that are essential for humans, other species, and the proper functioning of the planet as a whole (Borkey *et al.* 2005). Freshwater biodiversity is already being lost at a rapid rate (Vaughn and Hakenkamp 2001) and the impacts of microplastic pollution act only to exacerbate this decline. When biodiversity is lost, the ecosystem services that result from biodiversity are also lost.

The ecosystem services provided by freshwater can be categorized as provisioning services, regulatory services, cultural services, and supporting services. Provisioning services include provision of water for consumptive use, provision of water for non-consumptive uses such as power generation and transport, and provision of aquatic organisms for food and medicines. Regulatory services include maintenance of water quality through natural filtration and treatment, buffering against floods, and erosion control. Cultural services include recreation, tourism, and existence values. Lastly, supporting services provided by freshwater include the pivotal role freshwater plays in nutrient cycling and maintenance of primary production, the role of freshwater organisms in predator-prey relationships, and the contribution of freshwater to overall ecosystem resilience. Human well-being is directly reliant on freshwater, as is the well-being of many other species. However, the crucial ecosystem services provided by freshwater environments are threatened by its pollution, including pollution by microplastics (Borkey *et al.* 2005). Despite 71% of the earth's surface being covered by water, roughly 97% of this is salt water. Furthermore, over 68% of total freshwater is inaccessible in ice and glaciers. Only 1.2% of all freshwater is surface water, which includes lakes, swamps, marshes, and rivers (Perlman 2016). By continuing to contaminate surface water with microplastics (as well as other forms of pollution), humans are threatening/degrading a finite resource that is already in very short supply.

All life depends on freshwater, and by degrading it we not only threaten our own existence, but also the existence of all life on earth.

Sources of Microplastic Pollution

Personal Care and Cosmetic Products

One major source of microplastic pollution is the use of microplastics in PCCPs (personal care or cosmetic products) such as face and body washes. Ingredients in these personal care products considered to be microplastics consist of synthetic polymers and/or copolymers (i.e. plastics), are solid non-liquid particulates less than 5 mm in diameter, are insoluble in water, and are non-biodegradable. The incorporation of microplastics in PCCPs started in the 1960s as a cost saving measure and remains prevalent today, with constant innovation finding new uses for incorporating plastics—both soluble and insoluble—into products. Following the lead of the pharmaceutical industry, which uses microplastics to coat capsules and pills, the cosmetic industry is increasing the use of synthetic polymers and microplastics in their products as a cost-saving measure instead of using more expensive, natural ingredients. Prestigious innovation awards even exist within the PCCP sector in order to encourage and reward novel applications of plastic in such products (UNEP 2015).

Microbeads and other insoluble microplastic ingredients in PCCPs will most often be listed as polyethylene, polypropylene, or nylon within the product's ingredient list (NYSOAG 2015a). Microplastics in personal care products are most commonly understood as functioning as exfoliants. However, in addition to acting as exfoliants, plastic ingredients may actually serve a variety of functions in PCCPs including viscosity regulators, film formers, bulking agents, glitters, fragrance beads or fresheners, and as a way to prolong shelf life by trapping degradable active ingredients in the particle matrix of the non-biodegradable plastics (UNEP 2015).

Nylon, for example, is included in a diversity of products such as mascara, nail polish, bath products, deodorants, face makeup, lipsticks, moisturizers, skin care products, and sunscreen products. It acts as an absorbent in its capacity to absorb or soak up liquids, a bulking agent in its capacity to increase the volume of a product, as a film former in its capacity to form a thin coating upon drying, and as an opacifying agent to reduce the transparency of a product's appearance. Polyethylene can commonly be found in eyeliners, mascara, eye shadows, eyebrow pencils, lipstick, face powders and foundations, as well as in skin cleansers and skin care products. Like nylon, it can be used as a bulking agent and a film former. When included in toothpaste, polyethylene polishes the teeth. Microbeads made of polyethylene are also commonly used for the purpose of exfoliating, smoothing, or polishing the skin (Cosmetics Info 2016). Microbeads and other microplastics contained in rinse-off PCCPs are too small to be captured by current wastewater treatment infrastructure, thus eventually entering waterways via wastewater effluent or runoff after land application of sludge.

Microbeads from PCCPs are a serious source of microplastic pollution. It has been estimated that 808 trillion microbeads are washed down the drain each day in the U.S., with 8 trillion of these microbeads passing directly into aquatic environments via discharged wastewater effluent while the other 800 trillion accumulate in sewage sludge (Schlanger 2015). Cosmetics currently account for between 3 to 4% of all microplastic emissions, and microplastic use in PCCPs is continuing to increase globally (Plastic Soup Foundation 2016). A single bottle of exfoliating face wash, such as the Neutrogena Deep Clean Exfoliating Scrub, contains approximately 360,000 microbeads (Blomberg 2015) and a single bottle of sunscreen has been shown to contain approximately 100 billion microscopic plastic particles. While sunscreen is not a rinse-off PCCP it can still contaminate waterways when people wearing sunscreen swim in oceans, waterbodies, or waterways (Plastic Soup Foundation 2016). In a typical shower gel analyzed in a laboratory for polyethylene particulates, there was roughly as much plastic material in the gel by weight as there was in the plastic container it came packaged in (UNEP 2015). As the use of microplastics in PCCPs continues to proliferate, so too will the quantity of PCCP-derived microplastic pollution.

Synthetic Textiles

Another important source of microplastic pollution is microscopic plastic fibers that enter the wastewater stream from washing synthetic textiles such as blankets and clothing (ASC Worldwide Microplastics Project 2015; Browne *et al.* 2011). Synthetic textiles are produced from synthetic fibers, which are derived from petroleum. Synthetic textiles include materials such as nylon, fleece, polyester, polypropylene, polyamide, acrylic, and rayon. Natural fibers, on the other hand, are fibers that are found in nature, such as wool, cotton, and silk. Synthetic fibers can be produced easily and cheaply with a guarantee of complete purity in the fiber, which is why many textile manufacturers now use synthetic fibers over natural fibers. Synthetic fibers also allow for creation of more versatile and stylistically unique clothing by enabling manufacturers to control and alter properties of the clothing such as tensile strength, heat-resistance, dirt-resistance, and insulating ability (Greener Cleaner 2015). Synthetic fibers are also commonly used in non-garment textiles such as blankets. When synthetic textiles are washed in domestic washing machines, microscopic plastic fragments (less than 5 mm in size) are removed from the textiles and enter into the wastewater stream. A single synthetic garment can produce over 1900 fibers per wash, thereby attributing a large proportion of microplastic contamination to the washing of synthetic textiles (Browne *et al.* 2011). Moreover, microfibers such as those produced from washing synthetic textiles are thought to be the most harmful form of plastic pollution (Wright *et al.* 2013b). Similar to microplastics contained within PCCPs, the plastic fibers produced from washing synthetic textiles are too small to be captured by current wastewater treatment infrastructure, thus entering waterways via wastewater effluent or runoff after land application of sludge. There is currently no legislation in the U.S. that addresses this microplastic source.

Land Application of Sewage Sludge

The use of microplastic-containing PCCPs and the washing of synthetic textiles release large quantities of microplastics into the wastewater stream. Previous assessments of global plastic pollution in marine environments found that the quality of waste management systems, including wastewater treatment, is one of the most important factors in determining which countries contribute the most to plastic marine waste (Jambeck *et al.* 2015). Wastewater treatment plants, also known as sewage treatment plants or water pollution control plants, are well established and regulated in the U.S. (NYSDEC 2016). These facilities remove significant amounts of plastic macrodebris; however, current wastewater treatment infrastructure in the U.S. is not capable of removing microplastics from the wastewater stream due to the miniscule size of the plastics (Blomberg 2015; Eriksen *et al.* 2013; Rochman *et al.* 2015; Schlanger 2015). In the Unites States, three levels of wastewater treatment are typically carried out at wastewater treatment plants: primary treatment, secondary treatment, and tertiary treatment (The World Bank Group 2016) (Figure 5).

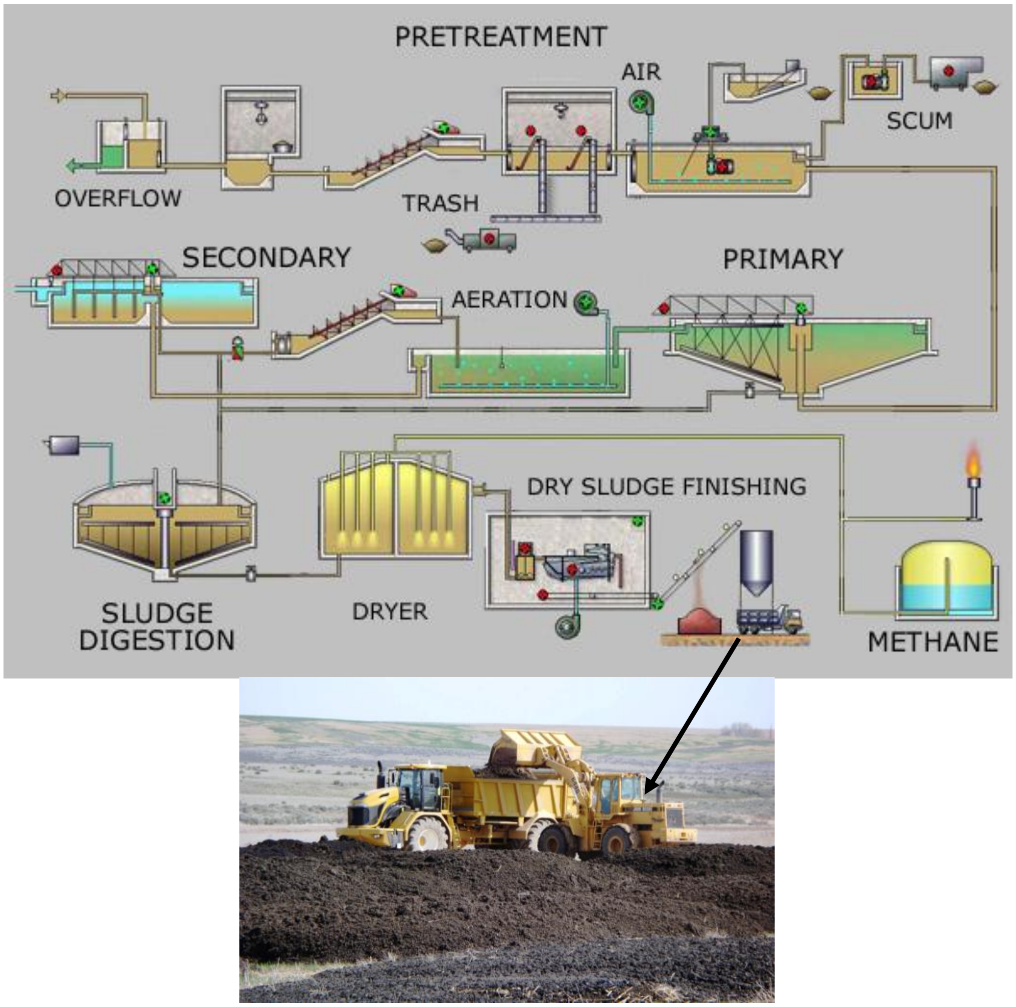

Figure5. Simplified process flow diagram for a typical large-scale wastewater treatment plant and the dry sludge that is produced through the treatment process and applied to land.

Primary treatment is a form of mechanical treatment designed to remove suspended and floating solids from raw sewage and wastewater. This stage of treatment includes screening to trap and remove solid objects, as well as sedimentation, driven by gravity, to remove suspended solids. Primary treatment is successful in removing 50 to 60% of suspended solids present in the wastewater stream. The next stage in the treatment process is secondary treatment. Secondary treatment is a form of biological treatment designed to remove dissolved organic matter that escapes removal during primary treatment. This is achieved through the use of microorganisms, which consume the organic matter as food. After being treated with these microorganisms, the wastewater proceeds to settling tanks in which secondary sedimentation takes place to remove more of the suspended solids. Secondary treatment is successful in removing 85% of suspended solids present in the wastewater stream (The World Bank Group 2016). Following secondary treatment, wastewater can proceed through optional tertiary treatment. In tertiary treatment, technological and chemical techniques are used to remove other forms of contaminants that remain after secondary treatment, such as dissolved nutrients like nitrogen and phosphorous. Tertiary treatment is successful in removing 99% of the impurities (not including microplastics) from wastewater, but it is energy intensive and requires a high level of technical know-how, ultimately increasing the operating costs of wastewater treatment plants. Disinfection is a common final step in wastewater treatment in which water is treated with chlorine, or less commonly ultra-violet radiation, prior to discharging the effluent (The World Bank Group 2016). Disinfection is an important step in wastewater treatment because it kills pathogenic bacteria in the water, which is an important process to protect human health (NYCEP 2016).

Every wastewater treatment plant in the U.S. is required to conduct primary and secondary treatment, but tertiary treatment is optional. Despite being optional, some form of tertiary treatment is common. Overall, the process of wastewater treatment functions to remove/reduce suspended solids, biodegradable organics, pathogenic bacteria, and nutrients from wastewater before the effluent is discharged into waterways and waterbodies (The World Bank Group 2016). Microplastics are not removed by current wastewater treatment infrastructure and methodology, which results in microplastics in the wastewater stream passing freely through the treatment process. These microplastics are either discharged in the wastewater effluent back into waterbodies and waterways, or the microplastics concentrate and accumulate in the sludge produced from the removal of suspended solids during primary and secondary treatment. Looking just at microbeads, which are one of several sources of microplastics in the wastewater stream, at a single wastewater treatment plant 1% of microbeads present in the wastewater stream are discharged with the water effluent (Schlanger 2015). This may not seem like a large source of pollution, but wastewater treatment plants in the U.S. are collectively capable of treating over 160 trillion liters of water each day. Estimates suggest that in the U.S., 808 trillion microbeads are washed down household drains each day. Thus, using a conservative estimate in which all U.S. wastewater treatment plants are operating at half-capacity (filtering 80 trillion liters per day collectively), this results in approximately 8 trillion microbeads being emitted directly into aquatic environments via the wastewater effluent on a daily basis. The other 800 trillion microbeads (99% of the microbeads present in the wastewater stream) accumulate in the sludge that is created during primary and secondary treatment (Rochman *et al.* 2015).

Sludge must also be processed before it is removed from the wastewater treatment plant. Sludge is processed in three stages: thickening, digestion, and dewatering. The sludge that is collected from the removal of suspended solids in primary and secondary treatment is 99% water. In order to thicken this sludge, thickening tanks are used, which allows for sludge to collect, settle, and separate from the water over a 24 hour period. The water is sent back to the start of the wastewater treatment process—primary treatment—while the settled sludge moves on to digestion, stage two of sludge processing. In digestion, the sludge is placed in heated, oxygen-free digester tanks for approximately 20 days. The digester tanks foster a favorable environment for anaerobic bacteria, which consume much of the organic matter present in the sludge (NYCEP 2016). Digested sludge is then pumped from sludge storage tanks to a dewatering facility. Stage three of sludge processing, dewatering, reduces the liquid volume of sludge by 90% through the use of large centrifuges that act to separate the water from the solids. The water is sent back to the start of the wastewater treatment process—primary treatment—while the sludge solid is treated with organic polymer to improve the consistency of the final “biosolid cake,” which is 25-27% solid (NYCEP 2016). No stage in sludge processing is able to detect or remove microplastics from the collected solids. The final processed sludge, full of undetected microplastics, leaves the wastewater treatment plant and is sent either to a landfill or an incinerator for disposal, or is applied to land as fertilizer (USEPA 1994).

When sludge that contains microplastics is applied to land it becomes a terrestrial source of microplastic pollution. Again, with only 1% of microplastics in the wastewater stream being discharged with the water effluent, this means that the other 99% of microplastics that enter wastewater treatment facilities end up accumulating in sludge (Schlanger 2015). Land application of sewage sludge in the U.S. is regulated at the federal level by the U.S. Environmental Protection Agency (EPA) and at the state level by state Departments of Environmental Conservation (DEC). According to the EPA, land application of sewage sludge includes the spreading, spraying, injection, or incorporation of sewage sludge, including any material derived from sewage sludge, onto or below the surface of land. The land application of sludge acts to improve the structure of the soil and acts as a fertilizer, supplying nutrients to crops and other vegetation. Sewage sludge is commonly applied to agricultural land, forests, reclamation sites, parks, highway median strips, golf courses, lawns, and home gardens.

However, sludge must be of a certain quality in order to be applied to land. The EPA has regulations to ensure such quality, including required testing to assess the presence of heavy metal pollutants, the presence of pathogens in the sludge, and the sludge’s attractiveness to disease vector organisms such as mosquitoes and rats. Sewage sludge that meets the strictest limits for these three quality assessment parameters is classified as Exceptional Quality (EQ) sludge. Both EQ and non-EQ sludge can be applied to land, but in order to protect human health, non-EQ sludge is applied to land that experiences less direct human contact (USEPA 1994). While testing of sludge is required by federal regulations, no tests related to the presence of microplastics in the sludge are currently required. The same holds true for state regulation of sludge application.

In New York State, land application of sewage sludge is regulated by the New York State Department of Environmental Conservation (NYSDEC). There are currently 21 permitted land application facilities for sludge in the state of New York. Permitting conditions are set to protect human health, animals, and soil biota. Permit conditions are developed and assessed based on soil characteristics, waste quality, pathogen reduction, waste stabilization, application location, nutrient loading, potential crop growth, and runoff potential (NYSDEC 2016a). There are 584 operational sludge treatment facilities within New York State, which receive the sludge from wastewater treatments plants and process it further before it is disposed of or applied to land. 360,000 dry tons of treated sludge are produced each year from these facilities. Of this, 17% of generated sludge is disposed of in landfills, 31% is incinerated, and 51% goes toward “beneficial uses” including direct land application. In New York State, 102 dry tons of treated sludge are applied directly to land each day. The NYSDEC tests sludge quality for metal pollution, pathogen pollution, and pollution of organic chemicals. Presence of microplastic pollution in treated sludge that is being applied to land is not regulated or discussed by the NYSDEC (NYSDEC 1999).

Neither federal nor state sludge land application regulations in the U.S. currently address the issue of sludge as a source of microplastic pollution. U.S. regulations and standards for land application are far less protective than regulations in place throughout Europe and Canada, leading some to feel that current U.S. sludge regulations do not adequately protect human health, agricultural productivity, or ecological health. Once pollutants enter soil via sludge, removal of the pollutants through soil remediation is difficult and costly, leading to long-term persistence of such pollutants within the soil (Harrison *et al.* 1999). In the case of microplastics, many of these microscopic particles eventually re-enter waterways via soil runoff. Sewage sludge as a terrestrial source of microplastic pollution has been well documented (Schlanger 2015; Rochman *et al.* 2015; Wagner *et al.* 2014) including as a source of microplastic pollution in North Country waterbodies (Eriksen *et al.* 2013). While wastewater treatment plants were designed to help keep waterways and waterbodies clean and to help preserve water quality, not all forms of water pollution are able to be removed by current wastewater treatment infrastructure. Thus, wastewater treatment plants become a source for microplastic pollution as microplastics enter aquatic environments when discharged in the wastewater effluent and when concentrated in sewage sludge which can then be applied to land as fertilizer.

<u>Macroplastic Degradation</u>

In addition to microplastics from PCCPs, synthetic textiles, and land application of sewage sludge, degradation of larger macroplastic is another major source of microplastic pollution in aquatic environments. Macroplastic, also referred to as plastic macrodebris, is a common form of litter/pollution in aquatic environments. Macroplastics are plastics that are larger than 5 mm in size. Macroplastics are especially prevalent in marine environments, but this source of microplastics is applicable to freshwater environments as well. When weathered, macroplastics present in water, such as plastic bags and plastic bottles, are broken down into smaller plastic pieces. This process can continue until the breakdown results in the formation and release of microplastics (ASC Worldwide Microplastics Project 2015). Many of the items purchased by modern consumers in the U.S. are made of plastics and most of these products are designed to be used only once (5 Gyres Institute 2016). This leads to large quantities of plastic in the waste stream. Only 5 to 10% of produced plastic is recovered (reused or recycled), with much of the remaining plastic washing into the world’s oceans. Plastic litter and debris also commonly wash into freshwater ecosystems such as lakes and rivers. Once in aquatic environments, macroplastics degrade into increasingly smaller particles, driven by exposure to the sun and the repetitive motion of waves. Thus, macroplastics become another source of microplastics, and since petroleum-derived plastics do not biodegrade this pollution persists in the environment (5 Gyres Institute 2016). The microplastic pollution from macroplastic degradation as well as the aforementioned microplastic sources enter aquatic environments and threaten biodiversity (Figure 6).

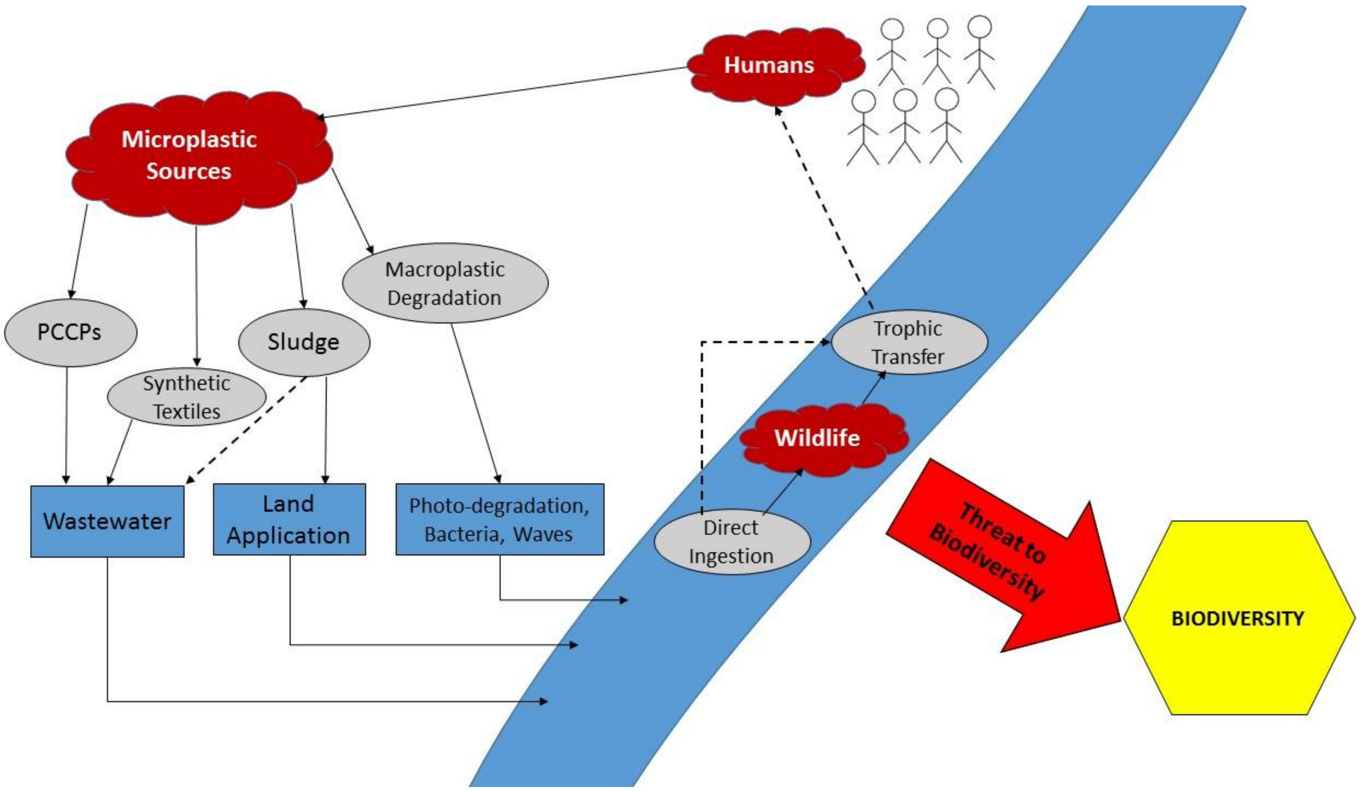

Figure 6. Conceptual model of sources and impacts of microplastic pollution.

The State of Microplastic Pollution in North Country Waterbodies

As of 2016, microplastic contamination has been confirmed in the Great Lakes, the St. Lawrence River, and Lake Champlain within the North Country (Figure 2). Microplastics have also been detected in the effluent of the Plattsburgh Water Pollution Control Plant, which drains into the Saranac River (Powell, personal communication[2]) and in the effluent of the Potsdam Sewage Treatment Plant, which drains into the Raquette River (Henninger, personal communication[3]). Additionally, a 2014 study conducted by the Office of the Attorney General in

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[2] Email Correspondence 24 March 2016

[3] Phone Interview 9 March 2016

New York State detected microplastic contamination in the effluent of 25 out of 34 wastewater treatment facilities sampled throughout the state, providing evidence that microplastics are being discharged into numerous waterbodies across New York State including the Great Lakes, the Finger Lakes, Lake Champlain, the Hudson River, the Mohawk River, the Delaware River, Long Island Sound, and the Atlantic Ocean (NYSOAG 2015b). Ultimately, further research is needed in order to properly assess the full extent of microplastic contamination of waterways and waterbodies within the North Country, however, it is likely that microplastic pollution is ubiquitous in the majority of North Country waterbodies that receive wastewater effluent.

The Great Lakes

Eriksen *et al.* (2013) conducted an open-water survey for plastic pollution within the Laurentian Great Lakes system and found that microplastics accounted for 81% of the plastic pollution found within the Great Lakes. Many of the microplastic particles collected from the Great Lakes were multi-colored spheres, which were found to be similar in size, shape, texture, and composition to microbeads from microplastic-containing PCCPs. Their study also found a higher than average concentration of microplastic particles at the sampling site that was downstream from two major cities, suggesting that microplastic pollution abundance is positively correlated with population (Figure 7). Particle counts within the lakes ranged from 450 up to over 450,000 microplastic particles per square kilometer. With counts in excess of 100,000 particles per square kilometer, this study found Lake Erie, one of the Great Lakes that borders New York State, to have the highest concentrations of microplastics (Eriksen *et al.* 2013).

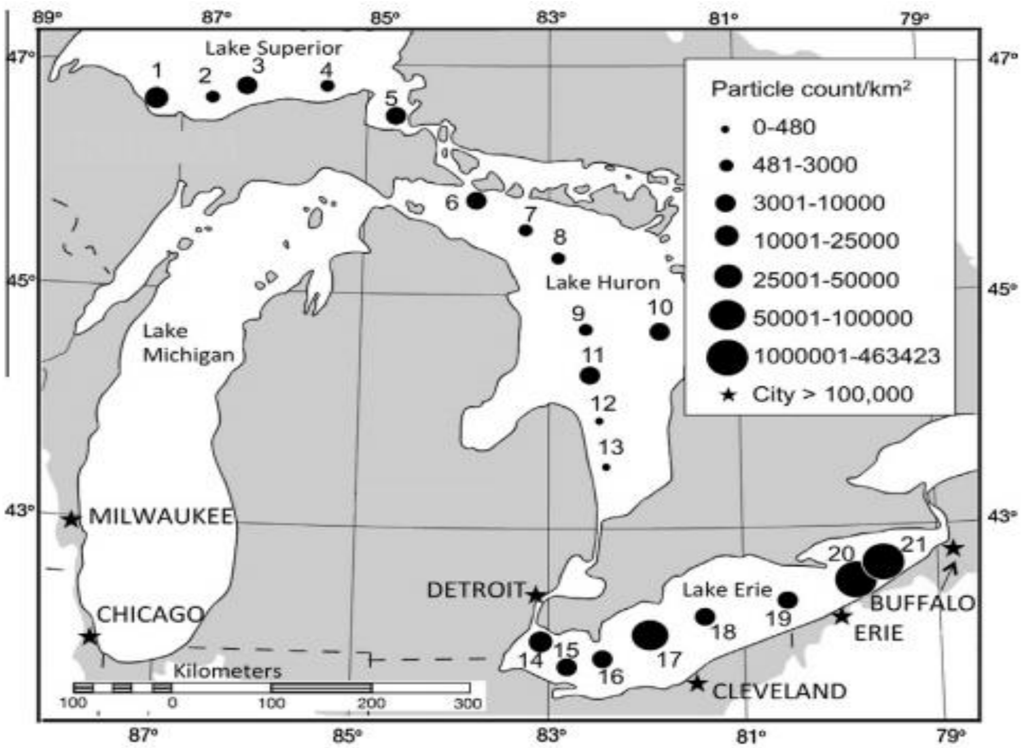

Figure 7. Distribution of plastic particles by count for 21 samples collected in three of the Laurentian Great Lakes. From Eriksen *et al.* 2013.

The St. Lawrence River

The first of its kind to investigate the presence of microplastics in North American freshwater sediments, a study by Castañeda *et al.* (2014) found microplastics to be abundant in St. Lawrence River sediment. The highest microbead densities found were comparable to microplastic concentrations found in the world's most contaminated marine sediments. Given the high local densities of microplastics in St. Lawrence River sediments, numerous fishes and macroinvertebrates are likely impacted, warranting further study (Castañeda *et al.* 2014). In addition to microplastic pollution, the St. Lawrence River faces a number of other threats including outdated dam management and industrial pollution, earning it a spot among America's top ten most endangered rivers (Wiedner and Kober 2016). Thus, this important and iconic North

Country waterway and the biodiversity it contains is seriously threatened, in part by microplastic pollution.

Lake Champlain

Microplastics found within Lake Champlain likely originate from microplastics in wastewater effluent discharged into the lake, from photodegraded macroplastics within the lake, and from the discharge of pre-production rubber particles. These particles were found to contaminate zooplankton populations within the lake. Currently, the Lake Champlain Research Institute is in the process of procuring a grant to continue their long-term (since 1994) sampling of zooplankton populations within Lake Champlain (Garneau, personal communication[4]). Lake Champlain faces other, potentially more pressing issues, including phosphorous pollution from runoff, and invasive species. Even so, advocates for Lake Champlain are hoping that the recent national ban on microbeads in PCCPs will help to address the issue of microplastic contamination before an insurmountable threshold of pollution is reached (Hirsch 2015).

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[4] Phone Interview 29 February 2016

IDENTIFICATION OF STAKEHOLDERS

Given the ubiquitous nature of microplastic pollution and the wide-reaching impacts that it has, there are a myriad of different people who have a stake in this problem and who should be involved in making decisions related to microplastic pollution. The environment as a whole, which is suffering from the adverse impacts of microplastic pollution, also has a large stake in this issue.

Manufacturers of Microplastic-Emitting Products

One of the primary stakeholders in the issue of microplastic pollution of freshwater is manufacturers of products that contain and/or emit microplastics. This includes PCCP manufacturers who produce products such as face wash, body wash, and toothpaste, which contain plastic-derived microbeads and other microplastics. Major PCCP manufacturers in the U.S. include companies such as Johnson & Johnson®, Neutrogena®, and Unilever® (see Appendix C for a more extensive list of PCCPs). Manufacturers of synthetic textiles would also fall within this stakeholder category, since washing synthetic textiles is a major source of microplastic pollution. Synthetic textiles include materials such as nylon, fleece, polyester, polypropylene, polyamide, acrylic, and rayon. Any clothing or textile company that makes products from synthetic fibers is contributing to the source of microplastics in the wastewater stream. Even more broadly, plastic manufacturers in general, as well as the petroleum companies who provide the petroleum used to create plastics, would also fall into this stakeholder category. In addition to PCCPs and synthetic textiles, degradation of macroplastic debris and litter in water is another major source of microplastic pollution. This includes manufacturers of plastic products such as plastic bags and plastic bottles, which commonly wash into waterways and waterbodies.

These manufacturers all have valid reasons for why they use micro- and macroplastics, yet the issue of microplastic pollution would not exist if there was no pollution source.

Consumers of Microplastic-Emitting Products

While the manufacturers of microplastic-emitting products are responsible for creating products that emit microplastics, consumers are a pivotal part of this equation as well. Manufacturers make the microplastic-emitting products, but consumers are the ones who purchase and use these products, which is the point at which the microplastics actually enter the environment. It is when face wash is rinsed off, when a fleece is washed, and when a plastic bottle is disposed of improperly that microplastics enter the wastewater stream and the environment. Without consumer demand, microplastic-containing products would not be produced, and without consumer use, the microplastics contained within these products would not be released. Many consumers are unaware about the environmental harm caused by microplastic-emitting products such as PCCPs and synthetic textiles, meaning that they are unknowingly contributing to microplastic pollution. Because we are examining microplastic pollution in North Country waterbodies, consumers of microplastic-emitting products from the North Country are of particular interest. Without change, cooperation, and the involvement of consumers, the issue of microplastic pollution will never successfully be resolved.

Politicians

Another important stakeholder in the issue of microplastic pollution is the politicians working to address the issue of microplastic pollution through legislation at the local, state, and federal levels. Microplastics are difficult to remove from aquatic environments, which means that one of the most effective ways of combating the issue is to remove the source of the pollution. Policy and legislation is a key way in which the source of microplastic pollution can be reduced, and ideally eliminated. At the local level of government, politicians at the county level are fighting for the passage of laws to protect waterways and waterbodies from the vagaries of microplastic pollution. Several counties in New York State, including Cattaraugus, Chautauqua, Erie, Suffolk, and Albany, have passed laws to address microplastic pollution at the local scale. Similarly, many states, through the work of state representatives, assemblymen and assemblywomen, and congressmen and congresswoman, have advocated for and/or passed state legislation to eliminate and reduce the use of microplastics in consumer products. For example, New York State Assemblywoman Michelle Schimel is the sponsor for the NYS *Microbead-Free Waters Act*, which would address the issue of microplastic pollution within the state of New York. Furthermore, there are also politicians at the federal level who were largely responsible for the recent passage of the *Microbead-Free Waters Act of 2015*, which mandates that PCCP manufacturers phase out the use of plastic microbeads by 2017. This includes U.S. Senator Kirsten Gillibrand, who introduced the act to Congress, and Congresswoman Elise M. Stefanik, who was a co-sponsor of the act. Politics play a significant role in many conservation issues, and without changes in policy brought about by the work of politicians, the issue of microplastic pollution will not be resolved.

Government Officials and Organizations

In addition to politicians, another part of the government that has a stake in the issue of microplastic pollution includes the government officials and organizations in charge of enforcing legislation and maintenance of clean waterways, including the enforcement and regulation of land application of sewage sludge. Such administrations exist at local, state, federal, and global levels and include organizations such as the NYSDEC, U.S. EPA, Environment Canada, and the United Nations (UN). Passing laws that dictate the removal of microplastic sources is an important first step, but without proper enforcement the laws will have no effect in alleviating the problem of microplastic pollution. Within the North Country, where several waterways and waterbodies are shared between the U.S. and Canada, such as the Great Lakes and the St. Lawrence River, enforcement must be coordinated between both governments. There also needs to be cooperation between local, state, and federal regulatory agencies in order to protect waterbodies throughout the United States, including the North Country. However, since microplastic pollution of freshwater is a global conservation problem, global organizations such as the UN also have a stake in the issue.

Environmental Groups and NGOs

Additionally, another relevant group of stakeholders in the issue of microplastic pollution are the environmental groups and NGOs advocating for a ban on microplastic use in manufactured goods and for the protection of waterbodies from pollution. This includes national organizations such as 5 Gyres Institute, as well as local North Country organizations such as Save the River. Environmental groups and NGOs such as these play a large role in educating people about microplastic pollution. They are also responsible for driving campaigns to enact policy changes. For instance, 5 Gyres Institute developed the “Ban the Bead” project, which helped to educate consumers and gain support for the *Microbead-Free Waters Act of 2015*. Environmental groups and NGOs work alongside the general public and politicians to put pressure on governments and manufacturers of microplastic-emitting products, acting as a key intermediary between several other stakeholder groups.

Scientists / Researchers

Conservationists in the form of scientists and researchers who are focused on studying, uncovering, and working to remedy the ecological impacts of microplastic pollution are another important stakeholder. Science is a key tool for informing policy and enacting change. It is easy to say that microplastic pollution is detrimental to the environment, but unless you have evidence to support this claim, politicians and government officials are not going to listen. This is where the scientists and researchers come into play. Particularly impactful researchers in the field of microplastic pollution, especially in the North Country, include Dr. Danielle Garneau from SUNY Plattsburgh, Dr. Sherri Mason from SUNY Fredonia, and Dr. Marcus Eriksen, Director of Research and Co-founder of the 5 Gyres Institute. The work of these conservationists is crucial for educating the public about microplastic pollution and informing policy to combat microplastic pollution.

Wastewater Treatment Plants and Sludge Land Application Facilities

Wastewater treatment plants also have a stake in this issue, as do sludge land application facilities and owners of land upon which sludge is applied. Because wastewater treatment plants are unable to remove microplastics from the wastewater stream, they become a major source of microplastic pollution. Microplastics enter waterbodies when discharged with the effluent from the wastewater treatment plant. The microplastics that are not discharged with the effluent accumulate in sewage sludge, which is treated and processed before being applied to land or disposed of in landfills or incinerators. When sludge contaminated with microplastics is applied to land, the microplastics can eventually enter aquatic environments via runoff. The majority of wastewater treatment plants are poorly funded and retrofitting the plant infrastructure to remove microplastics is not realistic. Land application of sewage sludge is poorly regulated and does not take into account the impact that land application of sludge has on microplastic pollution. Because wastewater treatment plants and land-applied sludge are part of the problem, they also need to be part of the solution, hence the inclusion of this stakeholder group.

General Public/North Country Residents

Another important category of stakeholders when addressing the issue of microplastic pollution is the general public, who may be impacted by microplastic pollution of waterbodies used for recreation, fishing, and/or tourism. Waterbodies and waterways hold intrinsic and instrumental value for many people, and are important components that contribute to a person's livelihood and quality of life. Many North Country residents recreate in North Country waterbodies, some rely on North Country waterbodies for food, for instance subsistence fishing and/or commercial fishing, and North Country tourism in certain regions is strongly driven by the draw of pristine waterbodies and waterways. Microplastic pollution threatens both the instrumental and intrinsic value of waterbodies, which can have serious repercussions for the general public. Thus, North Country residents have an important stake in this issue.

Because North Country residents are a key stakeholder group in this issue, we utilized our market inventory and survey results to gain further insight into the presence of microplastics in the North Country and to assess the degree of concern and awareness of this issue within the North Country community.

Survey Results

A total of 233 respondents participated in our microplastics survey. Demographically, 76% of survey respondents were females, 22% of respondents were males, and 2% of survey respondents preferred not to disclose their gender or identified as other. The age of survey participants ranged from 18 years old to 70 years old, with an average age of 38 years old. Furthermore, 26% of survey respondents were students at St. Lawrence University, 22% of survey respondents identified as St. Lawrence University faculty, 27% of survey respondents identified as St. Lawrence University staff, and 25% of survey respondents identified as North Country residents.

As part of our survey we asked a series of questions to assess each survey participant's degree of environmental concern and environmental connectivity. The environmental concern scale was used to measure an individual's degree of concern for the environment (Dutcher *et al.* 2007). This consisted of a set of five statements about the environment, scaled one through five, where one represented strong disagreement with the statement and five represented strong agreement with the statement (Appendix B). Composite scores for this scale ranged from 5 to 25, where 25 represented the greatest degree of concern for the environment. The minimum score among survey respondents was 6, the maximum score was 25, and the average score was 22 (Table 1). Thus, overall we observed a high degree of environmental concern among survey participants.

Table 1. Minimum, mean (±StDev), and maximum scores for environmental concern (n=206).

Minimum	Mean	Maximum
6	**21.782** (±3.371)	**25**

Similarly, in addition to asking a series of questions to assess the degree of environmental concern among survey participants, we also asked a series of questions to assess each survey respondent's degree of environmental connectivity. The environmental connectivity scale was used to measure an individual's sense of connection with their natural surroundings (Dutcher *et* *al.* 2007). This consisted of a set of six questions—five statements about connection with nature, scaled one through five, where one represented strong disagreement with the statement and five represented strong agreement with the statement, as well as a final question in which survey participants were asked to select one of three Venn diagram options to describe their relationship with nature (Appendix B). Composite scores for this scale ranged from 6 to 28, where 28 represented the greatest degree of connectivity with the environment. The minimum score among survey respondents was 8, the maximum score was 28, and the average score was 22 (Table 2). Thus, overall we observed a high degree of environmental connectivity among survey respondents. The high degree of environmental concern and environmental connectivity observed among survey participants may help to explain other aspects of our survey results and reveals an environmentally-focused perspective for North Country residents and consumers of products that contain or emit microplastics.

Table 2. Minimum, mean (±StDev), and maximum scores for environmental connectivity (n=206).

Minimum	Mean	Maximum
8	**22.286** (±4.007)	**28**

In terms of availability of microplastic-containing PCCPs in the North Country, our face wash market inventory found microplastic-containing face wash products available for purchase at all four of the major North Country retailers sampled (Kinney Drugs, Rite Aid, Price Chopper, and Walmart). Among the four retailers, there was a staggering 215 different brands and formulations of face wash products available. Nearly 25% of the available products contained microplastics (Figure 8). Over 48% of the 110 different products that explicitly claimed to exfoliate with advertisements such as “microbeads exfoliate” and “deep exfoliation” contained synthetic plastic exfoliants, while the other 52% of exfoliating face wash products contained natural exfoliating ingredients such as oatmeal, sea salt, walnut shell, and jojoba beads (Figure 8). Polyethylene was the plastic ingredient listed in the majority of microplastic-containing face wash products. The face wash products that contained microplastics were commonly advertised as being age-defying (plastic is essentially used to fill in lines and wrinkles in the skin) or were categorized as scrubs rather than washes or cleansers. The worst-offenders in terms of producing microplastic-containing face wash products included Clean & Clear®, Neutrogena®, and Olay® (Appendix C). Each of these brands had at least seven different microplastic-containing face wash products readily available in the North Country stores sampled. The average price per ounce of microplastic-containing face wash products was $1.31, while the face wash products containing no microplastics cost, on average, $1.03 per ounce (Appendix C). This suggests that microplastic-free face wash products may actually be more affordable for customers, eliminating a potential incentive or rationale for purchasing face wash that contains microplastics.

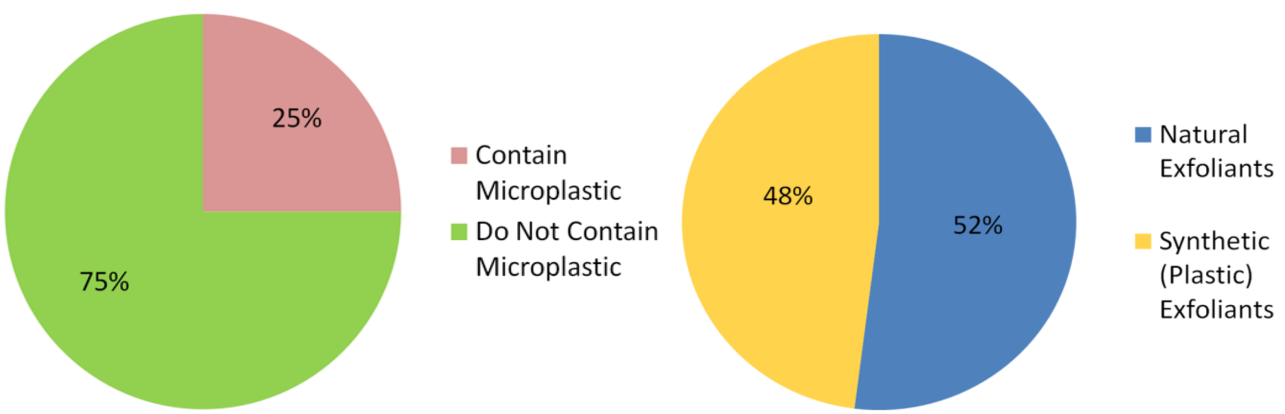

Figure 8. Prevalence of microplastic-containing face wash PCCPs (left) and use of synthetic exfoliants (right) in face wash brands sold at major North Country retailers.

Within our survey, we sought to assess the degree of brand consistency and brand loyalty among North Country consumers in terms of PCCP purchasing patterns. Seventy-four percent of respondents said that they did consistently use (meaning at least their last three purchases) the same brand of PCCPs, thus indicating a high degree of brand consistency among North Country consumers. However, there was not a high degree of brand loyalty, with 80% of survey respondents categorizing themselves as being either very or somewhat willing to switch their brand of PCCPs. Only a very small percentage (3%) of survey respondents said that they would be very unwilling to switch their brand of PCCPs (Figure 9). These findings indicate that many North Country residents/consumers would likely be willing to change their purchasing behavior in order to avoid using microplastic-containing PCCPs.

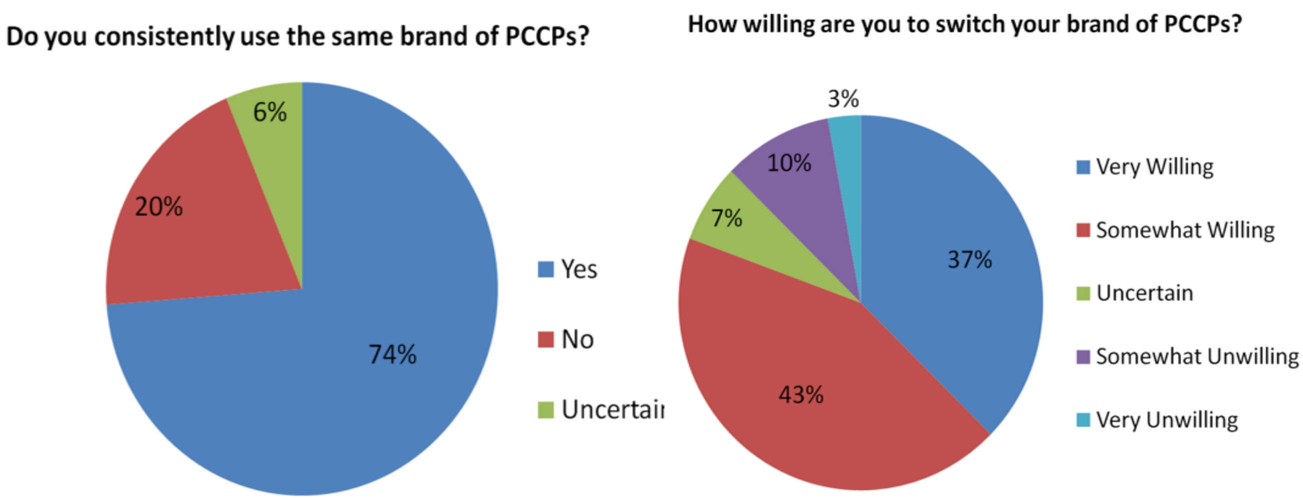

Figure 9. North Country consumer brand consistency (left) and brand loyalty (right).

Our next set of survey questions asked about the synthetic textile ownership and textile washing habits of North Country residents. Eighty-seven percent of respondents owned fleece garments, indicating a high degree of synthetic clothing present in the North Country. Respondents most often washed their fleece garments monthly or yearly. Additionally, 50% of respondents owned a polyester blanket or comforter which they washed monthly, and more commonly, yearly (Figure 10). With all of these synthetic textiles and even a moderate frequency of washing, this is discharging a significant amount of microplastics into North Country waterways.

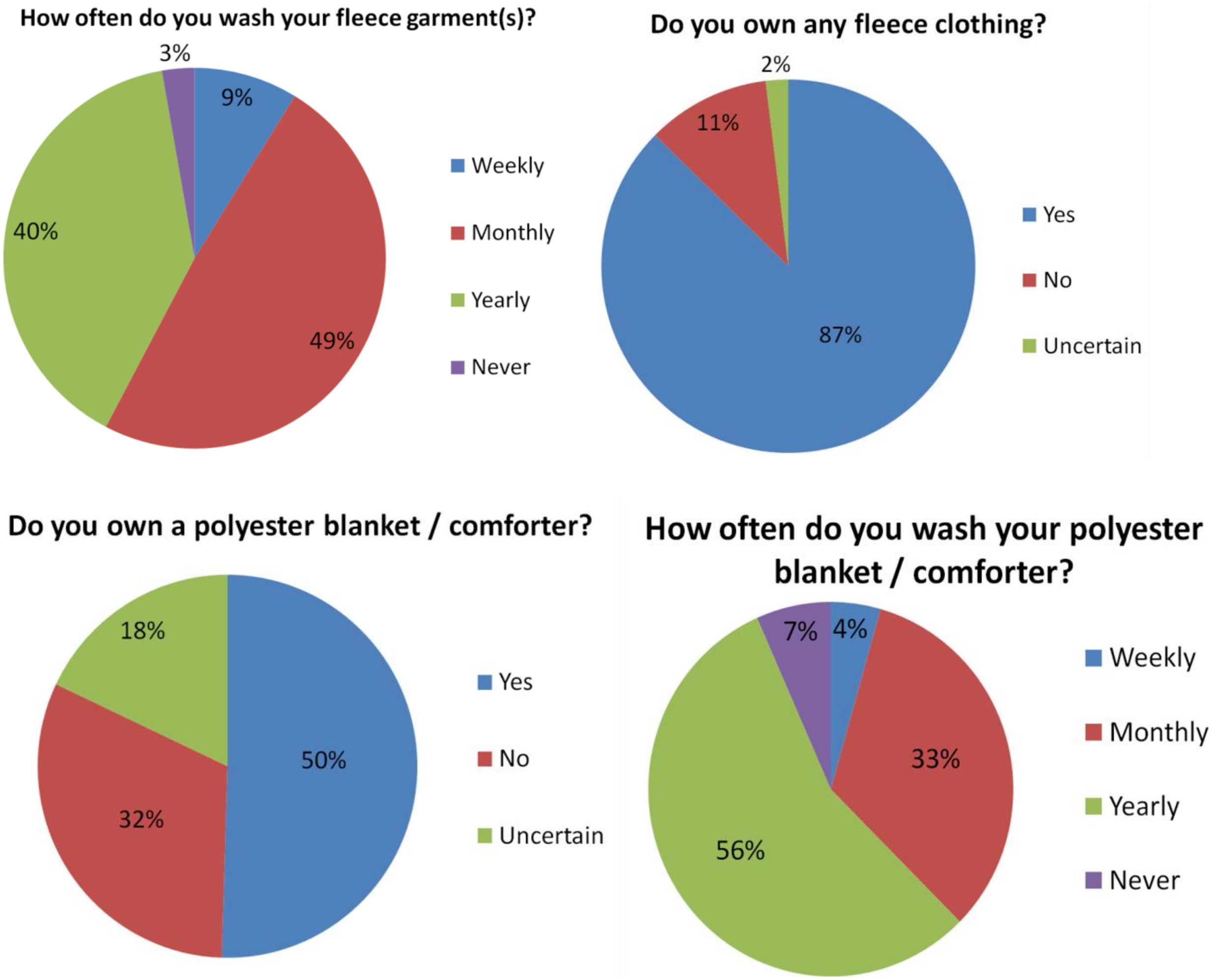

Figure 10. Degree of synthetic textile ownership and washing frequency among North Country residents based on survey responses.

One potential solution to help remedy the issue of microplastics emitted from washing synthetic textiles is to retrofit washing machines with a filter that catches microplastic fibers. There is currently one filter design—the Filtrol 160®— that costs about $140 (Septic Protector).We asked survey respondents if they would be willing to install a $140 washing machine filter in order to capture microplastic synthetic fibers. Fifty-two percent of respondents were willing, 16% were unwilling, and 32% were considered not applicable in that they did not own their own washing machine (Figure 11).

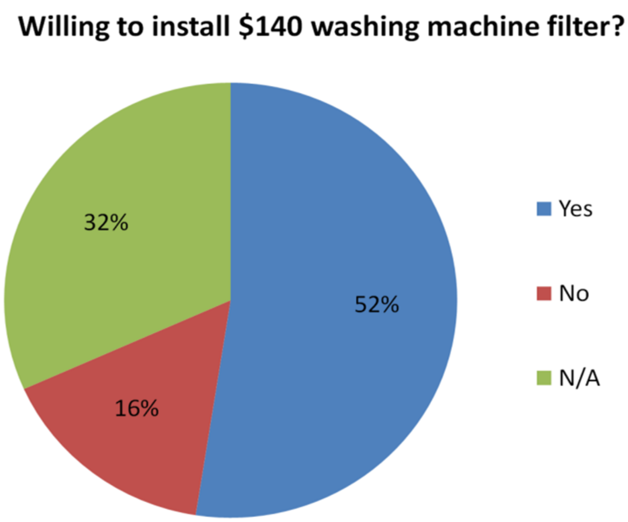

Figure 11. North Country residents' willingness to install washing machine filter (left) and filter model: the Filtrol 160® (right).

Additionally, a key aspect of preventing microplastic contamination is increasing consumer awareness. Currently there exists an app called "Beat the Microbead" (Plastic Soup Foundation 2016) which allows you to scan the barcodes of PCCPs with a smart phone to check for the presence of plastic ingredients. When asked if they were interested in downloading such an app, 61% of respondents indicated that yes, they were interested, 19% were not interested in the app, and 20% were considered not applicable in that they did not own a smart phone. A high proportion of respondents (84%) were aware of microbeads prior to taking this survey, while 16% had never heard of microbeads before. This high degree of awareness is not entirely surprising because microbeads are the most widely publicized source of microplastics. In terms of the 16% who had never heard of microbeads before and also in terms of the numerous sources and detrimental environmental impacts of microplastics, there is a fairly substantial knowledge gap and need for additional education in order to better inform as many North Country residents as possible.

We also asked survey respondents to rank their agreement with the statement that synthetic ingredients / products are superior to natural alternatives. The results from this survey question varied greatly among respondents. Fifty percent of respondents disagreed either strongly or somewhat with the statement, 36% were neutral, and 13% agreed that synthetic ingredients / products are superior to natural alternatives.

Because the ecosystem health and functioning of North Country waterbodies is threatened by microplastic pollution, we also attempted to assess the frequency with which North Country residents used North Country waterbodies for recreational activities such as canoeing, fishing, and swimming. Sixty-one percent of respondents utilized North Country waterbodies at least three times a year, 28% used them less than three times per year, and 11% of respondents never utilized North Country waterbodies recreationally. However, despite the variation in frequency of use, the overwhelming majority (83%) of respondents strongly agreed with the statement that protecting North Country waterways from environmental pollutants, including microplastics, is important (Figure 12).

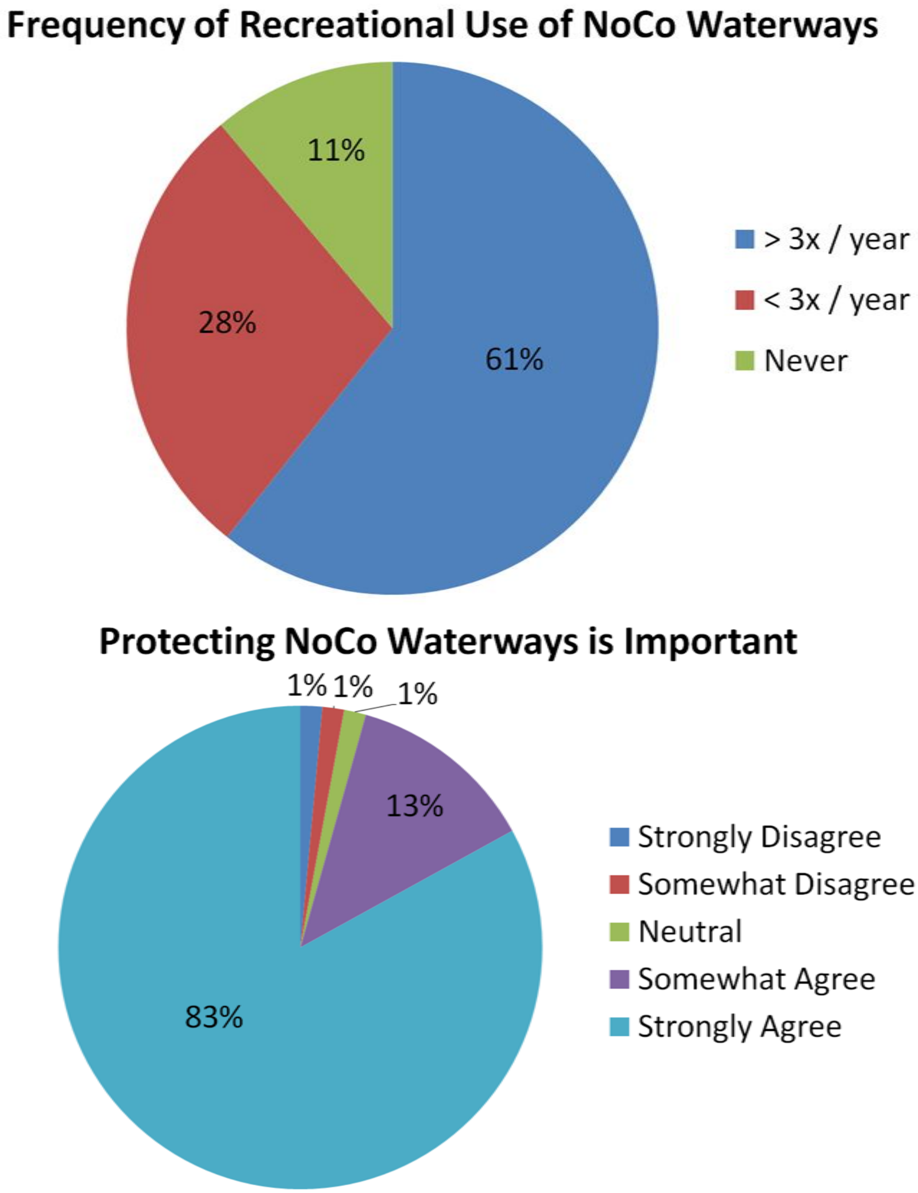

Figure 12. Frequency of recreational use of North Country waterbodies (above) and belief that it is important to protect these waterbodies from environmental pollutants including microplastics (below).

Lastly, we asked survey participants whether or not they were opposed to government legislation that mandated the removal of microplastics from PCCPs, with 83% of respondents stating that they were not opposed to such legislation.

The Environment

Lastly, in addition to the aforementioned stakeholders, the environment is also a primary stakeholder in the issue of microplastic pollution. The environment contains aquatic ecosystems and species which are adversely impacted and threatened by microplastic pollution, thus giving the environment a large stake in the issue. A variety of organisms (freshwater, marine, and terrestrial) at all trophic levels are adversely impacted by microplastic pollution. The adverse impacts on organisms and species threaten their existence and thus the existence of biodiversity. These impacts also threaten ecosystem health, function, and services that each organism/species contributes to. The health of the environment is what is at stake in the issue of microplastic pollution.

Overall, there exists a great deal of intersectionality between all stakeholders, and in order to bring about productive change to protect biodiversity from the harms of microplastic pollution, effective involvement, communication, and cooperation between all stakeholders is essential.

GOVERNMENTAL ISSUES

Because microplastic pollution of waterways is an issue with the potential to impact local, regional, national, and even international stakeholders, there currently exists many individuals and organizations at varying levels of government who have taken an active interest in the matter.

National

Perhaps the most well-publicized and impactful legislation regarding microplastic pollution of waterways is the *Microbead-Free Waters Act of 2015*. The bill, which sought to prohibit the sale or distribution of cosmetics containing synthetic plastic microbeads, was first introduced to the House of Representatives by Congressmen Frank Pallone, Jr. of New Jersey and Fred Upton of Michigan. Pallone is a member of the House Energy and Commerce Committee and Upton is the chairman of the committee. The bill was introduced to the U.S. House of Representatives on March 4, 2015 with an aim to enact the ban beginning on January 1, 2018. The bill was subsequently amended to enact the ban beginning July 1, 2017 and was later passed by the House on December 7, 2015. The bill was then introduced into the Senate under the sponsorship of Senator Kirsten Gillibrand of New York—a member of the Environment and Public Works Committee—where it was passed without amendment by Unanimous Consent on December 18, 2015. The bill was then presented to President Obama, who signed it into law on December 28, 2015 (MFWA 2015b).

Upon contacting Senator Gillibrand to discuss this legislation, she explained that the *Microbead Free Waters Act of 2015* prohibits the manufacture and introduction, into interstate commerce, of rinse-off cosmetics containing intentionally-added plastic microbeads, starting in 2017. She further explained that such a law will act as a "powerful new tool in our efforts to clean up New York's waterways.” In explaining the motivation behind such legislation, she cited an April 2015 report released by New York Attorney General Schneiderman's office which found that microbeads were present in 74% of water samples taken from 34 municipal and private wastewater treatment plants across New York State. The incapacity of wastewater treatment facilities to capture microbeads that are rinsed down the drain necessitates the removal of products containing plastic microbeads from the marketplace, Gillibrand explained. With the legislation passed, she says it is now time to begin focusing on “cleaning up the mess [microbeads] caused” (Gillibrand, personal communication[5]).

According to Stephanie Whyte, an outreach ambassador at 5 Gyres Institute, targeting consumers and producers using policy that introduces solutions focused on eliminating the source of microplastic pollution, like the national ban, is essential in bringing about an end to microplastic pollution and in eventually achieving 5 Gyres’ ultimate goal of regaining a plastic-free ocean. She explained that the national ban on microbead-containing, rinse-off PCCPs enacted by the *Microbead Free Waters Act of 2015* is exciting and useful in that it helps to remove the loopholes often present in similar state-based legislation. However, with a powerful and influential plastic lobby currently campaigning vigorously against any and all plastic-banning legislation, it was very fortunate that the microbead ban was passed, Whyte explained. A limitation of this legislation, however, is that every other country in the world can still use microbeads in their PCCPs. Therefore, given the connectivity of the world’s waterways, it is necessary to focus on helping other countries enact similar bans in order to bring about an effective end to microbead contamination of freshwater and marine ecosystems. While this piece

[5] Email Correspondence 4 March 2016

of national legislation is an important step in combating microplastic pollution of our waterways, Whyte points out that although the ban addresses microplastics found in PCCPs, there are many other entry points for microplastic contamination of waterways that legislation has yet to address. For example, within the U.S numerous attempts to ban plastic bags in grocery stores (which provide an additional source of microplastic pollution in aquatic environments through degradation) have been vigorously opposed and prevented by the powerful plastic lobby. Ultimately, more comprehensive legislation is needed within the U.S. in order to address all sources of microplastic pollution (Whyte, personal communication[6]).

State / County

There has also been a variety of microplastic-related legislation passed at the state and county level. For example, prior to the enactment of the *Microbead Free Waters Act of 2015*, a synonymous bill was sponsored in the New York State government by New York State Assemblywoman Michelle Schimel—a member of the New York State Assembly Committee on Environmental Conservation. The bill was introduced to and passed by the New York State Assembly in April 2015. However, the bill subsequently "died in the senate" in January 2016 (MFWA 2015a). According to Nicole Duckham, Assemblywoman Schimel's Chief of Staff, although there was some debate within the New York State Senate over how industries would be impacted by the ban, the bill ultimately failed to pass as a result of the congressional session ending (i.e. they simply ran out of time to pass the bill). However, due to a preemption clause within the federal microbead legislation, which prevents states from enacting stricter

[6] Phone Interview 1 April 2016

restrictions/regulations, the state legislation is now rendered unnecessary and void. With the federal ban enacted with the passage of the *Microbead Free Waters Act of 2015*, all states must now comply to halting the manufacturing of microbead-containing PCCPs by 2017 with an outright ban of all such products beginning in 2019 (Duckham, personal communication[7]).

Prior to any state or federal legislation, Cattaraugus, Chautauqua, Erie, Suffolk, and Albany counties within New York State had enacted bans on microbead-containing PCCPs on the basis that "'microbeads are a needless waste that wreak havoc on our wastewater infrastructure, and hurt our waterways and wildlife'" (Harding 2015). The specific wording of the national legislation, however, has allowed differing interpretations of the law to simultaneously reinforce and subvert the federal preemption clause when it comes to local microbead restrictions and timelines. As Frechette and Jackson (2016) explain: "Under one reading, the Act preempts any contrary state or local restrictions, setting all states and industry participants to the same schedule (a single-prong analysis)...An alternative reading of the statute, however, is that the preemption provision is tied to the tiered 'applicability' of the prohibitions. Thus, the Act only preempts state or local laws that contradict a prohibition that has 'begun to apply'"—meaning that instances of preemption could not occur until the national Act begins to be implemented in 2017. This allows counties, like Erie County in New York State, to maintain their pre-established timelines such as the February 2016 deadline implemented by county lawmakers. In a similar manner, other counties and states would be able to enforce or pass legislation prior to the 2017 deadline outlined in the national Act as long as they phase out any restrictions that are not identical to federal legislation once the federal legislation goes into

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[7] Phone Interview 10 March 2016

effect nation-wide in 2017. Such action counteracts Congress' stated goal of providing a uniform implementation timeframe in order to avoid a "patchwork of differing laws"—a position which industry participants strongly support (Frechette and Jackson 2016).

Canada

The Great Lakes and St. Lawrence River water systems comprise the largest shared water resource between the United States and Canada and contain over one-fifth of the world's fresh water supply. Given the immense ecological and economic value associated with this water system, international agreement and cooperation has long been an important factor in preserving the health and quality of the Great Lakes and the St. Lawrence River. Such cooperation was facilitated beginning in 1909 with the establishment of the International Joint Commission as part of the Boundary Waters Treaty, whose purpose was to prevent and resolve disputes between the United States and Canada. Additionally, in 1972 the Great Lakes Water Quality Agreement was signed by both countries (and later revised in 1978 and 1987) in order to control pollution and to clean up waste from industries and communities surrounding the lakes. Subsequently, Environment Canada and the U.S. EPA work jointly in monitoring and regulating the water quality of these shared waterways (CEC 2008).

On March 24, 2015, the House of Commons voted unanimously to take immediate measures to add microbeads to the List of Toxic Substances in the *Canadian Environmental Protection Act*(*CEPA*). Such regulations under the Act would prohibit the manufacture, import, sale, or offer for sale of microbead-containing PCCPs that are used to exfoliate or cleanse. More specifically, the proposed Order would add "synthetic polymer particles that, at the time of their manufacture, are greater than 0.1 μm and less than or equal to 5 mm in size" to Schedule 1 of

CEPA 1999. This means that microbeads would be classified as a toxic substance. Legally classifying microbeads as a toxic substance allows Canada's Minister of the Environment to propose risk management activities in order to assess and manage the potential environmental impacts of microbeads, which he prioritized. Subsequently, in July 2015, Environment Canada completed a comprehensive analysis of relevant scientific literature and existing knowledge regarding the environmental impacts of microbeads (Government of Canada 2015). In assessing the environmental presence and accumulation of microplastics in Canada, Environment Canada ultimately recommended that the Canadian Government add microbeads to the List of Toxic Substances under the *Canadian Environmental Protection Act* as a preventative measure to reduce the release of microbeads into the environment (Environment Canada 2015).

Currently, as the next step of the legislative process, Environment Canada is seeking public and stakeholder feedback on the proposal. The proposed legislation would prohibit the manufacture and import of microbead-containing PCCPs beginning on December 31, 2017. The sale of microbead-containing PCCPs would be prohibited beginning on December 31, 2018, at which point the ban would expand to include the manufacture and import of microbead-containing non-prescription drugs or natural health products used to exfoliate or cleanse. The sale of such products would be prohibited beginning on December 31, 2019 (Environment Canada 2016).

Because the Canadian Government has decided to regulate microbeads using the Chemicals Management Plan (CMP), which works to protect Canadians and their environment from the harmful effects of chemical substances, it may take a long time for the removal of microbeads to actually be implemented. According to Muhannad Malas, the Toxics Program Coordinator of the Canadian environmental action organization Environmental Defence, such delays are infuriatingly commonplace when it comes to managing the risks of chemicals categorized by the Canadian government as being toxic. As Malas explains, risk assessments have been completed for many toxic chemicals, but risk management measures for many substances have yet to be finalized. Therefore, Environmental Defence and other activist groups throughout Canada are calling for the newly-elected federal government to take swift action on the growing microbeads problem by overhauling the CMP in order to ban microbeads once and for all (Malas 2015).

Elsewhere in the World

Given the interconnectedness of our waterways, global transportation networks, and the growing ubiquity of the world plastic market, the issue of microplastic pollution spans far beyond the areas of concern within the North Country. In light of this global threat, the Netherlands, Austria, Luxembourg, Belgium, and Sweden have issued a joint call to ban the use of microplastics used in PCCPs on the basis of protecting marine ecosystems and seafood from contamination. Their statement was forwarded to the environment ministers of all 28 nations belonging to the European Union and states that the elimination of microplastics in products, and in particular in cosmetics and detergents, "is of utmost priority" (UNEP 2015). Although there is widespread global commitment to reduce plastic pollution in our oceans agreed upon at the Rio +20 UN Conference on Sustainable Development in 2012 as well as in the Honolulu Declaration drafted by global climate and marine scientists in 2012, there is still the need for international and national legislation that calls for an immediate response from all sectors and stakeholders in order to inform consumer behavior and eliminate / prevent plastic waste in aquatic environments (UNEP 2015).

A total of 4,360 tons of microplastic beads were used in 2012 across all European Union countries, Norway, and Switzerland, according to a survey by Cosmetics Europe. As a result of such findings and increasing concern over the emissions and deleterious impacts of microplastics, representatives from over 150 nations adopted a resolution on marine plastic debris and microplastics at the inaugural UN Environment Assembly in 2014. The resolution called for strengthened action and tasked the United Nations Environment Programme (UNEP) to conduct a global study on microplastic debris. Their findings were released a year later on World Oceans' Day in 2015 and recommends adopting a precautionary approach toward microplastic management, with an eventual phase out and ban of microplastic use in personal care products and cosmetics (UNEP NC 2015). To date, agreements and recommendations abound related to tackling the issue of microplastic pollution, but no concrete action has been taken by European governments. At this time, only the U.S. and Canadian governments have begun implementing policy changes and legislation that would start to address the concern of microplastic pollution, but such legislation delays action until far into the future and addresses only a very limited portion of the issue due to its singular focus on regulating microbeads in PCCPs.

DEVELOPMENT OF SOLUTIONS TO THE PROBLEM

Parameterizing Solutions

In order to adequately address and remedy the issue of microplastic pollution in North Country waterbodies, immediate action is needed in the form of consumer education/change and legislation in order to target and eliminate the sources of microplastic pollution in a timely manner. It is vital that such awareness and legislation target sources of microplastic pollution beyond the microbeads found in PCCPs. Additionally, due to the interconnectedness of waterways and waterbodies, a transnational approach is needed in order to effectively combat the truly global scope of this issue. This approach, too, needs to address more than just microbeads in PCCPs. Ultimately, an effective solution to the issue of microplastic contamination needs to halt further microplastic pollution of our waterways at its numerous sources and needs to begin to develop adequate strategies and technologies to be used in cleanup and remediation efforts. The protection of nature and biodiversity needs to be prioritized over all else, including human preference, convenience, and economy. Also, because much of the research regarding the environmental impacts of microplastic pollution has been focused primarily on marine ecosystems, additional research is needed in order to ascertain the true scope of pollution present and the subsequent impacts of such pollution in freshwater ecosystems throughout the North Country and beyond.

In order to be effective, we feel that an adequate solution to the issue of microplastic contamination of waterbodies needs to be timely, comprehensive, inexpensive, and easily-adopted. First, in order to be timely, an adequate solution must bring about change in both consumers and legislation that halts and eliminates the sources of microplastic pollution in the short-term rather than the long-term. For example, legislative bans that will take multiple years to go into effect are not fast-acting enough. Immediate change is necessary if biodiversity is to be protected. Secondly, in order to be comprehensive, consumer change and legislation must be ubiquitous and global in application. Because waterways and waterbodies are interconnected, stopping microplastic pollution at a local, state, or national level will not be enough. Microplastic pollution needs to be stopped globally if biodiversity is to be protected. Thirdly, in order to be inexpensive, the costs of eliminating the sources of microplastic pollution need to fall on the manufacturers of microplastic-emitting products such as PCCPs, synthetic textiles, and plastic waste products. Additionally, government subsidies to help pay for the necessary technology to protect waterbodies from microplastic pollution are needed to make such technologies affordable. The costs of eliminating microplastic pollution cannot and should not fall on consumers. Fourthly, in order to be easily-adopted, an adequate solution must require minimal changes to lifestyle and, once again, must place the burden of change on producers of microplastic-emitting products rather than on consumers. Overall, an effective solution to microplastic pollution must eliminate all sources of microplastics in order to prevent future pollution and must include an effective strategy for removing the microplastics that are already present in aquatic environments. Ultimately, an adequate solution must prioritize the protection of nature and biodiversity above all else.

Identification and Evaluation of Potential Solutions

Based on extensive literature analysis, interviews with various politicians, researchers, activists, and other relevant stakeholders, and the survey responses from North Country residents, we have developed several potential solutions, each with their own positive and negative aspects.

Solution 1- Eliminate All Sources of Microplastic Pollution

PCCPs: One way in which the source of microplastic pollution can be eliminated from PCCPs is through effective legislation that bans the presence of plastic microbeads in all rinse-off PCCPs. Such legislation would include banning microplastics from face washes, body washes, toothpastes, makeup, and any other PCCP that contains plastic ingredients. This solution is feasible because the burden and costs of such legislation would fall on the manufacturers of microplastic-containing PCCPs. Additionally, Canadian and U.S. politicians have shown resounding support of such legislation by already enacting legislation to mandate the removal of plastic microbeads from PCCPs and to classify microbeads as a toxic substance. However, even though national legislation exists within the United States banning the use of plastic microbeads in PCCP products beginning in 2017, more sweeping and immediate action is needed in order to effectively combat the multitude of adverse impacts resulting from microplastic pollution of our waterways. Additionally, such legislation is under constant threat and restraint from the powerful plastic lobby, which seeks to subvert and prevent any plastic-banning government action, and is limited by the absence of bans in other countries (Whyte, personal communication[8]). Legislation raises public and international awareness, places the burden of changes and costs on multi-billion dollar corporations, and mandates uniform implementation while requiring very little to no changes in everyday lifestyle for the public. However, legislation fails to meet the requirement of being timely and fails to bring about immediate action, while also failing to address other sources of microplastic pollution beyond microbeads. Ultimately, legislation offers a symbolic solution

[8] Phone Interview 1 April 2016

to the issue of microplastic contamination but fails to bring about change in the time scale and the scope that is needed.

If and when PCCP manufacturers are made to comply with PCCP microbead bans, there exists numerous natural and biodegradable alternatives that can be used as exfoliants in PCCPs in place of plastic microbeads. Such natural alternatives include jojoba beads (which are made from natural wax), salt, walnut shell, oatmeal, charcoal, sugar, other nut shells, enzymes found naturally in fruits such as pineapple and papaya, rice, bamboo, apricot seeds, and powered pecan shells (Yeomans 2014; Adams 2014;DuFault 2014). These natural, biodegradable alternatives are currently used in several PCCP brands, primarily products that advertise being environmentally-friendly and made from 100% natural ingredients (Appendix C). According to dermatologists, these natural alternatives are 100% as effective as plastic microbeads at exfoliating and are likely even better exfoliants because they are gentler on skin and are not uniformly round, therefore adding additional texture (Adams 2014).

Ideally, companies such as Johnson & Johnson® that have promised to phase out the use of microbeads in their PCCPs would be held accountable for following through on their promises. These companies would ultimately be responsible for bearing the costs of phasing out microplastics and would be held accountable through fines and fees if they fail to comply with their promises and/or nationally-mandated legislation. Johnson & Johnson® CEO Alex Gorsky claims that the company takes their commitment to citizenship and sustainability "very seriously." On the issue of microbeads, the company's annual Citizenship and Sustainability Report explains that they have stopped developing new products containing polyethylene microbeads and aim to remove them from their products by the end of 2017 (Johnson & Johnson 2014). Consumer pressure is needed in order to demand faster action, increased transparency, and legitimate time lines for microplastic phase out in PCCPs from companies that claim to care about the environment. Company actions need to do more than simply comply with federal legislative mandates.

Another possible solution to eliminate microplastic pollution from PCCPs is to forgo bathing and brushing teeth until we can be sure that our PCCPs do not contain plastics. However, this solution is not only unhygienic, but is also unrealistic and unfeasible in that it would require a huge change in lifestyle that the majority of people would be unlikely to accept. A more realistic and therefore effective solution is to focus on educating consumers so that they can make informed decisions and avoid purchasing microplastic-containing PCCPs. Consumers, if in possession of a smart phone, can use the “Beat the Microbead” App to scan their personal care products prior to purchasing them to check if they contain microplastics. Also, consumer education can be brought about through increased transparency in the ingredient lists on PCCPs. This solution is especially important in helping to combat continued pollution in light of the existing legislation that allows microplastic-containing PCCPs to continue to be manufactured and sold for years to come before companies must comply with the nationally-mandated phase out. Consumer awareness and education is key because many people are willing to change their purchasing habits once they become aware of the problem (Whyte, personal communication[9]). The need for increased consumer awareness holds true wherever PCCPs are sold, including within the North Country.

An additional strategy that can be used to address the source of microplastics from PCCPs is hosting “Scrub Swaps” whereby consumers can exchange unused or partially-used

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[9] Phone Interview 1 April 2016

microplastic-containing PCCPs for an alternative brand or product that does not contain plastic (Whyte, personal communication[10]). Such Scrub Swaps have been successfully carried out in the state of California and create a low-cost way for consumers to switch their PCCP brands. Scrub Swaps also ensure that consumers are correctly educated about which products contain microplastics and which do not. Furthermore, microplastic-containing PCCPs collected at Scrub Swaps can be properly disposed of in lined landfills, which ensures that these products and the microplastics they contain never enter the wastewater stream (5 Gyres Institute 2016).

Governments can play a role in helping to disseminate knowledge, with resources like the pamphlet issued by New York Attorney General Eric T. Schneiderman, which aims to help consumers choose personal care products that do not contain known forms of plastic pollution. The pamphlet, titled "*Microbeads Megaproblem: Keep Your Home Free of Plastic Microbeads*," recommends that consumers check the ingredient list, check their products against a list of products known to contain microbeads, and consider downloading the "Beat the Microbead" App to scan the barcode of PCCPs in order to find out if they contain microplastics before purchase (NYSOAG 2015a).

Synthetic Textiles: Microbeads in PCCPs are not the only source of microplastic pollution. In fact, they comprise only a small part of the large array of microplastic pollution sources (Garneau, personal communication[11]). Another main source of microplastic pollution, as discussed previously, is the release of microplastic fibers that come from washing synthetic textiles. One way in which the source of microplastic pollution can be eliminated from textiles is

[10] Phone Interview 1 April 2016

[11] Phone Interview 29 February 2016

through the use of natural fibers rather than synthetic fibers. Synthetic textiles are produced from synthetic fibers, which are derived from petroleum. Synthetic textiles include materials such as nylon, fleece, polyester, polypropylene, polyamide, acrylic, and rayon. Natural fibers, on the other hand, are fibers that are found in nature, such as wool, cotton, and silk (Greener Cleaner 2015). Textiles, such as blankets and clothing, have been made from natural fibers long before the arrival of petroleum-derived synthetic fibers. Natural fibers do not shed in the same way that synthetic fibers do, and natural fibers are able to biodegrade in the environment, unlike synthetic fibers which are not biodegradable. If all textiles were produced using natural fibers rather than synthetic fibers, synthetic textiles as a source of microplastics would be eliminated. However, there are limits to the amount of natural fibers available for mass textile production, and natural fibers do not offer the same degree of style, versatility, and functionality as synthetic textiles.

Another way in which the source of microplastic pollution can be eliminated from textiles is through the installation of microplastic-catching filters on washing machines. One example of a filter that catches microplastic particles from wastewater is the Filtrol 160®. This filter is manufactured by a septic protection company. The filter is available to purchase and install on domestic washing machines and is used by laundromats and government facilities throughout the U.S. The Filtrol 160® is a reusable filter that attaches to the discharge hose of washing machines. The filter removes non-biodegradable synthetic fibers like polyester and nylon, as well as sand, hair, and pet fur, which helps to prevent drain clogging and protects septic system health (Septic Protector). Use of this filter would allow for synthetic textiles to be washed without contributing to the problem of microplastic pollution.

Macroplastics: Additionally, enhancing recycling programs to properly remove a larger proportion of plastics from the waste stream would help reduce the presence of macroplastic debris in aquatic environments. Improvements in recycling could be made by incentivizing consumers to recycle and by better educating consumers on how to properly dispose of their plastic waste. Legislation that mandates the removal of certain sources of macroplastics, such as plastic grocery bags and water bottles, could also help to reduce the amount of macroplastic contamination that acts as a source of microplastic pollution. Reducing the amount of plastic used in packaging, either through consumer demand, producer incentives, or legislation, can also reduce the load of plastic pollution entering our waste stream and our environment. Lastly, designing plastic-containing products to be used multiple times rather than for a single use would also help to eliminate significant quantities of plastic from the waste stream. The less plastic present in our waste stream, the less chance it has of entering aquatic systems where it becomes a source of microplastic pollution.

Solution 2- Equip Wastewater Treatment Facilities with Microplastic-capturing Technology

Another possible solution is to retrofit wastewater treatment infrastructure in order to capture microplastics before they can enter waterways or accumulate in sludge. This solution would adequately target sources of microplastic pollution including microplastics in PCCPs as well as microplastics from synthetic textile laundering. If all relevant North County wastewater treatment plants could be retrofitted, this solution would be of a proper scope as well. However, trying to capture and remove microplastics from the wastewater stream is not feasible for many North Country wastewater plants. As Dave Powell, the Chief Plant Operator at the Water Pollution Control Plant for the City of Plattsburgh, explains: “Trying to treat the issue here at this facility would be very difficult in capturing microbeads. The kind of filtering we are talking about in microns would create a system of filters that could easily be clogged since we see on average about 7 milligrams per liter (mg/L) of solids being discharged on a daily basis" (Powell, personal communication[12]). However, it is not only the volume of wastewater being treated and the likelihood of microfilter-clogging that render this solution unfeasible, but there is the larger issue of the fact that such technology does not exist. Even if such technology did exist, the funds for affording such technology and the infrastructural upgrades it would require are not currently available. As Powell further explains, many facilities do not have the technology in place to capture microbeads and other microplastics. Although such technology may eventually become a reality, it will likely take a long time for technology to be developed that is affordable and effective (Powell, personal communication[13]).

Although studies conducted by researchers from SUNY Plattsburgh and the New York State Attorney General's Office have confirmed the presence of microplastics in the effluent of North Country wastewater plants, such as the Potsdam Sewage Treatment Plant, many plant operators have only recently been made aware the issue and note that there is still nothing they can do about it because their plants are simply not set up to remove microplastics (Henninger, personal communication[14]). Ultimately, Chief Operator of the Potsdam Sewage Treatment Plant, Bob Henninger, argues that microbeads and other sources of microplastic pollution need to be taken off the market to fix this problem. The solution is stopping the source of the plastics, not filtering them out, he explained. He also noted that one of the biggest obstacles facing wastewater treatment plants is in obtaining the funding needed to modernize plants and to

[12] Email Correspondence 24 March 2016

[13] Email Correspondence 24 March 2016

[14] Phone Interview 9 March 2016

incorporate higher levels of treatment (Henninger, personal communication[15]). Therefore, even if microplastic-filtering technology existed, it would be too costly to retrofit treatment plants. The 2015 Microbeads Report commissioned by the New York Attorney General's Office corroborates such a claim, concluding that even if effective treatment technologies are found to be available, the potential cost and time necessary to retrofit wastewater treatment plants with such technology is likely to be substantial. Therefore, prevention of use in personal care products and elimination of other microplastic-emitting sources are more efficient approaches to address the emerging problem of microplastic pollution in New York State waters (NYSOAG 2015b).

Solution 3- Remove Microplastics from Polluted Environments

Another solution to alleviate the deleterious environmental impacts of microplastic pollution is to remove microplastics and other accumulated macroplastic debris from waterways and waterbodies. There currently exists a multitude of inventions, such as vacuums and various solar-powered suction devices, which can be used to remove accumulated plastic trash from aquatic environments. Removing macroplastic debris is important in eliminating the microplastic fibers and fragments that result from the degradation of larger plastic waste. However, these clean-up devices often indiscriminately suck up and filter water, which poses a major issue of bycatch when numerous macro- and microorganisms are taken in by the vacuums along with the plastic (Whyte, personal communication[16]). Further, some of these devices may only be effective in capturing macroplastic debris and would be unable to filter out microplastic fibers and

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[15] Phone Interview 9 March 2016

[16] Phone Interview 1 April 2016

particles from the water (Garneau, personal communication[17]). There is also the additional potential negative effect of plastic removing / remediation technology being used to justify and rationalize continued pollution of our waterways. Also, removing the plastic from our marine and freshwater ecosystems would generate a massive amount of plastic waste that we would then need to figure out what to do with once it has been collected (Whyte, personal communication[18]). Therefore, although remediation technology such as aquatic vacuums has been developed, many of these devices are still in the prototype stage and have their own environmental issues such as bycatch. Additionally, such technology would have to be applied at a very large scale in order to be effective, which is not yet feasible given the currently limited development of remediation technology.

Feasible Solutions

No single solution will adequately solve the issue of microplastic contamination of waterbodies in the North Country. What is needed is a solution that combines the best elements from all of the aforementioned potential solutions (in terms of feasibility, ease of implementation, affordability, timeliness, appropriate scale, and consumer willingness to change). An adequate solution to the issue of microplastic pollution must act to protect biodiversity and must also be timely, comprehensive, inexpensive, and easily-adoptable.

Legislation is a feasible solution, shown by the fact that legal acts have already been passed by the U.S. and Canadian governments that begin to address the issue of microplastic

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[17] Phone Interview 29 February 2016

[18] Phone Interview 1 April 2016

pollution. There also exists a multitude of international agreements and a general consensus among countries globally that action is needed to address the growing issue of macro- and microplastic contamination of marine and freshwater ecosystems. Therefore, it is feasible that legislation can continue to be implemented and utilized as a strategy to bring about the necessary changes. However, drafting, enacting, and eventually enforcing legislative measures is a time-consuming process. Furthermore, the need for ubiquitous global legislation to address and eliminate the sources of microplastic pollution will be incredibly difficult to achieve. Therefore, while legislation is useful in achieving long-term change, alternative action is needed in order to address the issue of microplastic pollution in the short-term. Ideally, this action would entail forcing the manufacturers of microplastic-emitting products, such as PCCPs, synthetic textiles, and other sources of plastic pollution, to act now rather than later to remove the threat caused by their products. However, the plastic lobby is a powerful force, and many of those responsible for producing plastic-based products are multi-billion dollar corporations driven largely by profit. For this reason it is unlikely that manufacturers will willingly change. Therefore, rather than mandating responsible production, it would be more feasible to encourage responsible consumption through education.

Consumer education is essential for eliminating the sources of microplastic pollution. Although manufacturers are responsible for creating the products that emit microplastics, consumer use of such products is what actually emits microplastics into aquatic environments. Education is a particularly important solution due to the inadequacies of technological solutions to microplastic pollution. The potential to implement technology to capture microplastics in wastewater treatment plants and to remove plastics from contaminated ecosystems is not a feasible solution because such technology is too costly and/or not yet developed. Cleaning up and removing plastics from our waterways would be ideal, but new technology and strategies are needed to remove plastics from our waterways in a way that does not further threaten and impact biodiversity through bycatch and ecosystem disturbance. Continued innovation and invention should most definitely be pursued, but in the meantime consumer education and outreach is the more feasible approach.

Consumer education is a feasible and effective solution. It fits the requirements of an adequate solution in the fact that it can be timely, comprehensive, inexpensive, and easily-adopted. Consumers can become better educated about microplastic-emitting products through the use of government-issued pamphlets and smart phone apps such as “Beat the Microbead.” If consumers become better educated on this topic, they can choose PCCPs that do not contain microplastics, they can choose clothing made from natural fibers rather than synthetic fibers, they can install a filter on their washing machine to catch the microplastic fibers that are emitted when synthetic textiles are washed, and they can increase their efforts in recycling plastic waste so that less macroplastic debris enters aquatic environments. While these consumer education solutions are adequate as a whole, several of them may not be feasible for particular consumers. For instance, the “Beat the Microbead” App is free to download, but can only be used by consumers who have a smart phone. Similarly, the choice to install a filter on washing machines to catch microplastic fibers can only be implemented by consumers who own their own washing machine and who can afford the $140 cost of the filter. Therefore, while consumer education is a feasible solution overall, it may not be a feasible solution for all consumers.

Best Solutions

The best solution to the issue of microplastic contamination in North Country waterbodies combines the most feasible aspects for each of the aforementioned tiers of solutions—legislation, technology, and education (Figure 13). However, due to the serious limitations faced by legislative and technological solutions, we feel that the most promising solution to the issue of microplastic pollution rests in the hands of the consumers. In order to effectively eliminate microplastic pollution in a timely, comprehensive, and feasible manner, consumers need to be made aware of the issue and informed on alternatives to combat the issue. This includes utilizing technology like the "Beat the Microbead" App, as well as other platforms, to inform consumers before they buy. It also includes implementing technology in the home, such as installing microplastic filters on washing machines. The more widely such technology is utilized, the less costly and more accessible it will become. The solution also lies in future innovations, with a definite need to continue to research and innovate in order to develop filtering and remediation technology that is inexpensive and effective. Ultimately, stopping microplastic pollution at its source—or in this case its numerous sources—rather than trying to take action after the fact is essential. Eliminating the sources of microplastics through a combination of global legislation, affordable and innovative technology, and consumer education acts to prioritize nature over human preference, convenience, and economy, and is therefore successful at protecting biodiversity from the threat of microplastic pollution.

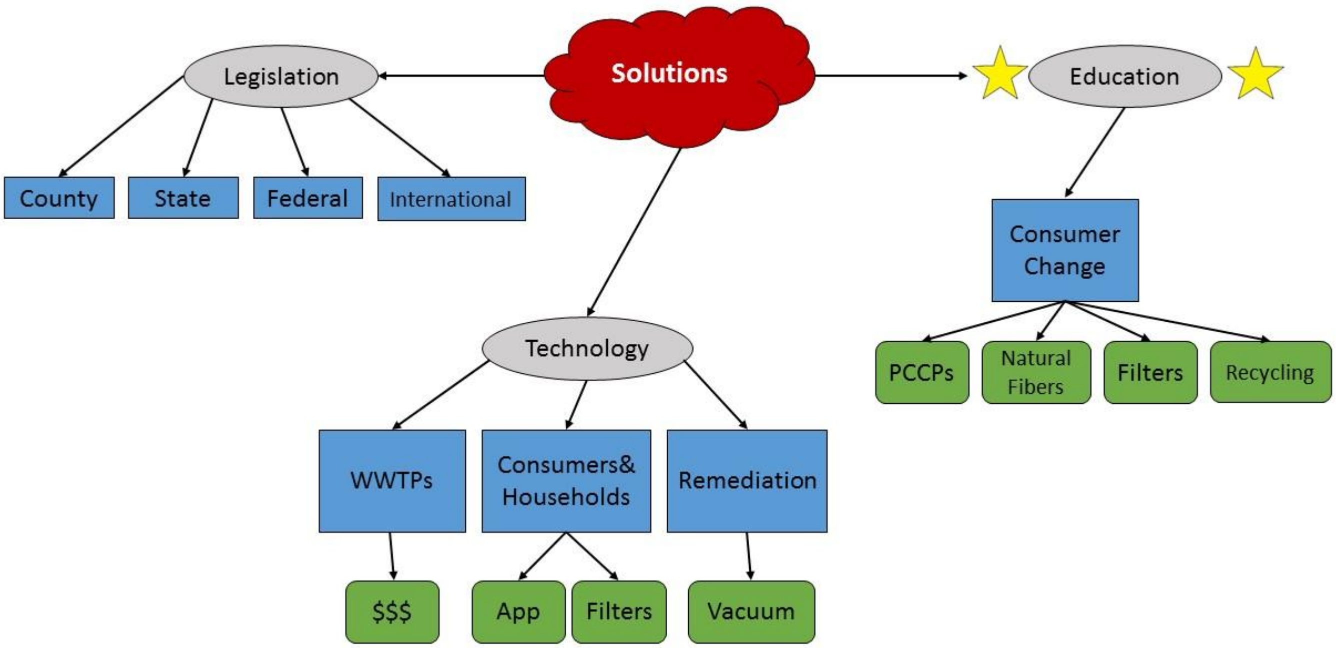

Figure 13. Conceptual model of solutions to the issue of microplastic pollution in the North Country.

EASE OF IMPLEMENTATION

The aforementioned solutions, in the form of legislation, technology, and education, will be palatable and achievable for the majority of stakeholders, with the main exception being the manufacturers of microplastic-emitting products. Because the proposed solutions will put the most burden, financially and logistically, on manufacturers, there is likely to be push back and a lack of cooperation from this stakeholder party. These corporations make billions of dollars annually and can afford the costs associated with mandated production changes. Communicating the serious threat that microplastics pose to biodiversity as well as the consumer demand for more environmentally-friendly products may help manufacturers of microplastic-emitting products be more willing to change. Also, in order to be successful, manufacturers of microplastic-emitting products will need to be closely monitored and fines will need to be implemented if manufacturers are not complying with legislative mandates. The regulation of legislative compliance in the U.S. will likely fall to state DECs and the EPA, which means that more funds and personnel need to be allocated to these organizations so that regulation can be successful. The same applies for international and global regulation related to microplastic pollution.

For consumers of microplastic-emitting products that are initially unwilling to change, better education and incentives can be used to achieve the behavioral changes that are needed to protect the environment. Many consumers will change their behavior if they have information that incentivizes them to do so. A key way to disseminate this information is through our education system. Shockingly, even as Conservation Biology majors in our senior year of college, we had never heard of this issue or of any of its solutions prior to embarking on this case study project. Much like the classic environmental issue of climate change, which is now widely incorporated across curricula, including a unit on microplastics in pertinent science classes at all levels of education could bring about the large-scale dissemination of knowledge that is needed to enact change. Numerous educational resources including blogs, websites, scientific literature, and videos exist on the issue of microplastic pollution. Thus, at the very least, a basic introduction to the issue could be achieved in as little as two minutes with an informative video.

Through education, consumers could be encouraged to purchase non-synthetic textiles or to limit the washing of their synthetic textiles. Similarly, retailers of washing machines could be incentivized to inform their customers of the potential benefits of installing a microfiber filter on their washing machine to increase the longevity and functionality of septic systems and drainpipes. Additional incentives for such technology could exist in the form of government subsidies or tax breaks. Likewise, laundromats and government facilities could also be incentivized or mandated to install filters in order to capture non-biodegradable fibers like polyester and nylon. As long as the costs are kept low for consumers, we believe they will be willing to make the necessary changes. The changes required by consumers are not radical and would only require slight adjustments to daily lifestyles, thus making implementation at the consumer level feasible and relatively easy.

Legislation could also be enacted to mandate the inclusion of filters in commercial laundering operations and within government facilities. However, it is necessary that the filter technology be improved and expanded, as currently there exists only one filter model that costs over $100 (Septic Protector). Thus, it is also necessary to promote collaborative innovation. Innovators could be encouraged to develop plastic-capturing and plastic-removing devices through the use of innovation contests and grants. Ultimately, by combining legislative, technological, and educational solutions implementation will be successful and the threat posed to biodiversity from microplastic pollution will be stopped.

IMPLEMENTATION PLAN

Education/Outreach

In implementing our multifaceted, education and source-based solution, we first recommend reaching out to North Country environmental groups at local universities, high schools, and middle schools in order to gain student and faculty support/involvement. We would encourage these school groups, students, and educators to incorporate brief units or lectures on microplastic pollution into their school curricula. We would also be able to utilize the manpower found within these school groups to host Scrub Swaps, table at local stores near the PCCP aisles to hand out pamphlets and encourage shoppers to download the free "Beat the Microbead" App. We also recommend continuing to inform North Country residents about the issues, solutions, and current status of microplastic pollution via local news outlets, websites, and blogs.

Legislation

Once these groups of North Country students, educators, and interested residents are informed, they could also be used to conduct letter writing and phone call campaigns to lawmakers encouraging the drafting of continued, stricter, faster-acting, and more comprehensive microplastic legislation. It is important that the consumers and residents of the North County show their support for the *Microbead-Free Waters Ac*t, but also make it clear to our politicians that further action is needed. Given the ambiguous preemption restrictions of the national legislation, targeting county legislators to promote the implementation of stricter and timelier microbead bans may also be particularly effective. Connecting legislators with researchers is a key aspect of generating more comprehensive and effective legislative solutions, as currently the political rhetoric incorrectly promotes the idea that banning microbeads in

PCCPs is enough, when really numerous researchers agree that this is only scratching the surface of the larger issue of microplastic pollution (Garneau, personal communication[19]). Grassroots student groups could join with existing environmental organizations, such as Save the River, to increase manpower and resources.

Innovation and Continued Research

North Country environmental organizations, students, researchers, and residents could seek funding from private donors and grants to expand research on microplastic pollution in freshwater ecosystems within the North Country as well as to encourage technological innovation in the realm of microplastic-capturing and remediation technology. In addition to encouraging lawmakers to implement the aforementioned legislative actions, these groups could also gain the support of local and regional politicians and legislators in allocating funds to support these efforts.

[19] Phone Interview 29 February 2016

CONCLUSION

By allowing microplastics to enter our freshwater and marine ecosystems, whether consciously or unconsciously, we have enabled something that is literally microscopic in size to become an issue of global proportion. As persistent environmental pollutants with a proclivity for toxin accumulation, the presence of microplastic contamination in our waterways threatens a myriad of species, including humans, and has the potential to wreak economic and ecological havoc on our marine and freshwater ecosystems. As an issue that is ubiquitous in scale, combating microplastic pollution requires comprehensive legislation, research, and outreach that targets pollution at its numerous sources.

As with many human-caused environmental issues, microplastic contamination of freshwater ecosystems within the North Country, and the larger issue of plastic pollution in freshwater and marine ecosystems all over the world, will take a collaborative effort to resolve. This effort needs to focus on education, prevention, research, innovation, and remediation. Of the myriad of issues threatening to destroy our planet's biodiversity, microplastic pollution is an issue that can be resolved if we act quickly and prudently. Although the full extent of this issue has yet to be adequately assessed and understood, immediate changes in consumer behavior like choosing microplastic-free PCCPs and installing microfiber-catching washing machine filters can have a major impact in helping our region, our country, and ultimately our world combat the consequences of the growing load of toxic plastic pollution that is accumulating in our environment. For this reason microplastic pollution must be stopped at its source immediately in order for biodiversity to be protected. Failure to act now may allow the issue of microplastic pollution to forever alter and degrade the environmental landscape and functionality of our planet’s freshwater and marine ecosystems.

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Figure 3:

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Figure 4:

A- Zooplankton http://www.doc.govt.nz/nature/native-animals/invertebrates/zooplankton/
B- Aquatic earthwormhttp://www.stroudcenter.org/research/projects/schuylkill/macroslideshow.shtm
C- Crayfish http://fullserviceaquatics.com/koi-pond/crayfish-for-your-pond/
D- Rainbow mussel http://www.dec.ny.gov/animals/87949.html
E- Atlantic blue crab http://news.uwlax.edu/blue-crab-discovered-a-long-way-from-home/
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Figure 5:

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Figure 7:

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APPENDICES

Appendix A. Interview Contact Information

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To contact by email: https://www.ccc-consumercarecenter.com/universal-contact-us/us-neutrogena-ucu/www.neutrogena.com
To contact by phone: 1-800-582-4048, 9AM to 7PM EST Monday-Friday

Johnson & Johnson®
To contact by email:https://www.ccc-consumercarecenter.com/universal-contact-us/us-safetyandcarecommitment-ucu/www.safetyandcarecommitment.com
To contact by phone: 1-800-361-8068,9AM to 7PM EST Monday-Friday

Unilever®
To contact by email: https://www.unileverusa.com/contact/contact-form/
To contact by phone: 1-800-298-5018, 8:30 AM-6:00 PM EST Monday-Friday

Appendix B. Copy of Survey Instruments

Survey Questions

Listed below are statements about your degree of environmental concern. Please indicate the degree to which you agree with each statement:

1. If things continue on their present course, we will soon experience a major ecological catastrophe.

1	2	3	4	5
SD	MD	U	MA	SA

2. The problems of the environment are not as bad as most people think.

1	2	3	4	5
SD	MD	U	MA	SA

3. We are fast using up the world’s natural resources.

1	2	3	4	5
SD	MD	U	MA	SA

4. People worry too much about human progress harming the environment.

1	2	3	4	5
SD	MD	U	MA	SA

5. We are spending too little money on improving and protecting the environment.

1	2	3	4	5
SD	MD	U	MA	SA

Listed below are statements about your connection to the environment. Please indicate the degree to which you agree with each statement:

1. I see myself as part of a larger whole in which everything is connected by a common essence

1	2	3	4	5
SD	MD	U	MA	SA

2. I feel a sense of oneness with nature

1	2	3	4	5
SD	MD	U	MA	SA

3. The world is not merely around us but within us

1	2	3	4	5
SD	MD	U	MA	SA

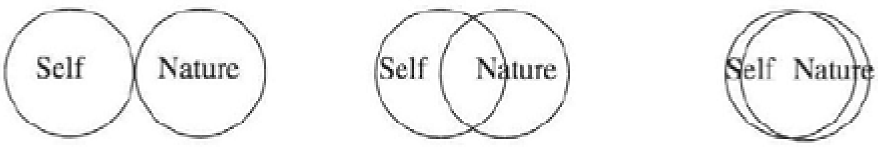
4. I never feel a personal bond with things in my natural surroundings, like trees, a stream, wildlife, or the view on the horizon

1 2 3 4 5
SD MD U MA SA

5. While in the outdoors, I have experienced a lessened sense of the distinction between myself and my natural surroundings

1 2 3 4 5
SD MD U MA SA

6. Select the Venn diagram that best represent your relationship with nature:



Please answer the following questions regarding your use and purchasing pattern of personal care products (toothpaste, soap, face wash, etc.):

1. Do you consistently (3 or more of your last purchases) use the same brand of personal care/cosmetic products?

   Yes No Unsure

2. How willing are you to switch your brand of personal care products?

1	2	3	4	5
Very unwilling	Somewhat unwilling	Uncertain	Somewhat willing	Very willing

3. Please select any of the following product brands that you use:

- Auromere
- Aveeno
- Biore
- Burt’s Bees
- Caress
- Cetaphil
- Clean and Clear
- Clearasil
- Dial
- Dove
- Garnier
- Ivory
- L’Oreal
- Neutrogena
- Noxema

- Olay
- St. Ive’s
- Store-brand cleansers (if so, write in which store)
- Suave
- Tom’s of Maine
- Other: (spot to write in brand)

4. From which retailer do you frequently purchase your personal care/cosmetic products? (Select all that apply):
   - Kinney Drugs
   - Rite Aid
   - Price Chopper
   - Walmart
   - Other: (spot to write in)

Please answer the following questions regarding potential textile sources of microplastics:

1. Do you own any fleece clothing?

   Yes No Unsure

2. How often do you wash your fleece garment(s)?

   Often (once per week)
   Occasionally (once per month)
   Infrequently (once per year)
   Never
   I do not own fleece clothing

3. Do you own a polyester blanket/comforter?

   Yes No Unsure

4. How often do you wash your polyester blanket/comforter?

   Often (once per week)
   Occasionally (once per month)
   Infrequently (once per year)
   Never
   I do not own a polyester blanket/comforter

5. Would you be willing to install a filter in your washing machine to catch microplastic fibers released from synthetic textiles for a cost of approximately $140.00?

   Yes No I do not own my own washing machine

Please answer the following questions regarding your awareness of microbeads:

1. Prior to taking this survey, had you ever heard about microbeads?

   Yes No

2. Would you be interested in downloading a free app that can be used to scan products to determine if they contain microbeads?

Yes   No   I do not have a SmartPhone

3. Are you opposed to government regulation that mandates the removal of microbeads from personal care products?

Yes   No   Unsure

1. How often do you utilize North Country waterbodies (lakes or rivers) for recreation (fishing, swimming, canoeing, kayaking, boating, etc.)?

Frequently (more than 3 times / year)   Infrequently (Less than 3 times / year)   Never

2. Please rank the degree to which you agree or disagree with the following statements:

It is important that North Country waterways and waterbodies are protected from degradation by human-released pollutants and contaminants such as microbeads.

1	2	3	4	5
SD	MD	U	MA	SA

Synthetic products/ingredients are more effective than natural products/ingredients.

1	2	3	4	5
SD	MD	U	MA	SA

Please answer the following questions:

1. How did you find out about this survey?

   e-mail   SLUWire   Facebook   Nature Up North

2. What is your gender?

Male   Female   Other   Prefer not to disclose

3. What is your age?

- spot to write in age

4. Which of the following do you identify as? (select all that apply):

SLU Student   SLU Faculty   SLU Staff   North Country Resident

Appendix C. Market Survey Data

Rite Aid: Canton, NY (Sampled February 20, 2015)

Product Name	Microplastic Status	Exfoliating Agent	Price	OZ	Advertising Claims
Burt's Bees Sensitive Facial Cleanser w/ Cotton Exfoliant	no	bark extract	9.99	6	99% natural
Burt's Bees Peach + Willowbark Deep Pore Scrub	no	ground peach stone, willow bark	8.49	4	99.9% natural, exfoliates
Neutrogena Naturals Purifying Pore Scrub	no	white willow bark, jojoba beads	8.49	4	94% natural, Nature Conservancy endorsed
Neutrogena Naturals Purifying Facial Cleanser	no	white willow bark	8.49	6	90% natural, Nature Conservancy endorsed
Neutrogena Fresh Foaming Facial Cleanser	no	n/a	7.49	6.7	
Neutrogena Ultra Gentle Daily Cleanser: Foaming Formula	no	n/a	10.49	12	
Neutrogena Deep Clean Cream Cleanser	no	n/a	7.29	7	
Neutrogena Deep Clean Facial Cleanser	no	n/a	7.29	6.7	
Simple Moisturizing Facial Wash	no	n/a	7.99	5	
SebaMed Liquid Face and Body Wash for sensitive skin	no	n/a	12.99	13.5	nearly 100% biodegradable
Rite Aid Renewal Skin Cleansing Cream	no	n/a	4.49	12	
Neutrogena: The Transparent Facial Bar	no	n/a	3.27	3.5*	
Cetaphil Gentle Skin Cleanser	no	n/a	14.29	16	
Rite Aid Renewal Gentle Skin Cleanser	no	n/a	9.49	16	
Olay Age Defying Classic Cleanser	microplastic	polyethylene	6.29	6.78	
St. Ive's Blemish Control Apricot Scrub	no	walnut shell, cornmeal	4.99	6	
Rite Aid Renewal Apricot Scrub Blemish + Blackhead Control	no	walnut shell, cornmeal	3.49	6	
St. Ive's Fresh Skin Apricot Scrub	no	walnut shell, cornmeal	4.99	6	
Rite Aid Renewal Apricot Scrub Fresh Skin Cleanse	no	walnut shell, cornmeal	3.59	6	
Neutrogena Oil-Free Acne Wash: Pink Grapefruit Foaming Scrub	yes	polyethylene	8.99	4.2	microbeads
Olay Regenerist Regenerating Cream Cleanser	microplastic	polyethylene	7.99	5	exfoliates
Rite Aid Renewal Daily Regenerating Cleanser	microplastic	polyethylene, apricot seed	5.99	5	exfoliates
Aveeno Positively Radiant Skin Brightening Daily Scrub	yes	polyethylene	8.49	5	microbeads
Rite Aid Renewal Bright Skin Daily Face Scrub	yes	polyethylene	6.29	5	
Aveeno Clear Complexion Foaming Cleanser	no	n/a	8.49	6	
Biore Pore Unclogging Scrub	yes	unknown	7.99	5	spherical beads
Purpose Gentle Cleansing Wash	no	n/a	6.99	8	
Rite Aid Renewal Daily Face Wash	no	n/a	4.99	6.5	
Neutrogena Oil-Free Acne Wash	no	n/a	7.49	6	
Rite Aid Renewal Oil-Free Acne Wash	no	n/a	5.79	6	
Rite Aid Renewal Blackhead-removing medicated scrub	yes	polyethylene	5.19	5	
Clean+Clear Continuous Control Acne Cleanser	no	n/a	7.49	5	
Clean+Clear Deep Action Cream Cleanser	no	n/a	6.79	6.5	
Clean+Clear Essentials Foaming Facial Cleanser	no	n/a	6.49	8	
Rite Aid Renewal Acne Wash Daily Scrub	yes	polyethylene	5.99	4.2	
Neutrogena Oil-Free Acne Wash: Pink Grapefruit Facial Cleanser	no	n/a	8.99	6	
Oxy Acne Medication Rapid Treatment Face Wash	no	n/a	6.99	6.25	

Price Chopper: Canton, NY(Sampled February 20, 2015)

Product Name	Microplastic Status	Exfoliating Agent	Price	OZ	Advertising Claims
Neutrogena Oil-Free Acne Wash	no	n/a	7.49	6	
TopCare Oil-Free Acne Wash	no	n/a	4.49	6	
Neutrogena Deep Clean Invigorating Foaming Scrub	yes	polyethylene	7.99	4.2	microbeads
Neutrogena Fresh Foaming Facial Cleanser	no	n/a	6.99	6.7	
Simple Smoothing Facial Scrub	no	n/a	6.99	5	exfoliates
Simple Moisturizing Facial Wash	no	n/a	6.99	5	
Noxzema Classic Clean Original Deep Cleansing Cream	no	n/a	3.99	12*	
Noxzema Classic Clean Moisturizing Cleansing Cream	no	n/a	3.99	12*	
Noxzema Classic Clean Original Deep Cleansing Cream	no	n/a	3.99	8	
Neutrogena Naturals Purifying Facial Cleanser	no	white willow bark	7.49	6	90% natural, Nature Conservancy endorsed
Neutrogena Oil-Free Acne Wash: Pink Grapefruit Foaming Scrub	yes	polyethylene	7.99	4.2	microbeads
Neutrogena Oil-Free Acne Wash Daily Scrub	yes	polyethylene	7.49	4.2	microbeads
Neutrogena Oil-Free Acne Stress Control Power-Clear Scrub	yes	polyethylene	7.99	4.2	microbeads exfoliate
Neutrogena Deep Clean Gentle Scrub	yes	polyethylene	6.99	4.2	microbeads exfoliate
Neutrogena Clear Pore Cleanser/Mask	no	n/a	7.99	4.2	
Neutrogena Deep Clean Cream Cleanser	no	n/a	6.99	7	
Clean+Clear Morning Burst Facial Cleanser	?	n/a	5.99	8	"bursting beads"
Clean+Clear Morning Burst Facial Scrub	yes	polyethylene	5.99	5	"bursting beads"
Clean+Clear Continuous Control Acne Cleanser	no	n/a	6.49	5	
Clean+Clear Deep Action Cream Cleanser	no	n/a	5.49	6.5	
TopCare Daily Pore Cleanser for Face	yes	polyethylene	3.99	5.5	"micro-scrubbers"
Clean+Clear Blackhead Eraser Scrub	yes	polyethylene	5.49	5	exfoliates
Garnier Clear Blackhead Eliminating Scrub	yes	polyethylene	7.99	5	infused w/ charcoal, microbeads
St. Ive's Blackhead Clearing Green Tea Scrub	no	n/a	4.39	6	"100% natural exfoliants"
St. Ive's Nourished and Smooth Oatmeal Scrub + Mask	no	walnut shell, oatmeal	4.39	6	"100% natural exfoliants"
St. Ive's Blemish Control Apricot Scrub	no	walnut shell, cornmeal	4.39	6	"100% natural exfoliants"
TopCare Apricot Scrub Acne Medication	no	walnut shell, cornmeal	3.49	6	
TopCare Apricot Scrub Refreshing	no	walnut shell, cornmeal	3.49	6	
Oxy Acne Medication Rapid Treatment Face Wash	no	n/a	5.99	6.25	
Biore Pore Unclogging Scrub	yes	unknown	7.99	5	spherical beads
Clearasil Ultra Rapid Action Daily Face Wash	no	n/a	7.99	6.78	
Clearasil Ultra 5 in 1 Exfoliating Wash	yes	polyethylene	8.29	6.78	"exfoliating wash"
Cerave Foaming Facial Cleanser	no	n/a	9.99	12	
Cerave Hydrating Cleanser	no	n/a	10.99	12	
Cetaphil Daily Facial Cleanser	no	n/a	11.99	16	
Cetaphil derma-control oil control	no	n/a	10.99	8	

foam wash					
Olay Regenerist Luminous Brightening Foaming Cleanser	no	n/a	8.49	6.7	
Olay Regenerist Regenerating Cream Cleanser	microplastic	polyethylene	5.99	5	exfoliates
Olay Age Defying Classic Cleanser	microplastic	polyethylene	4.12	6.78	
Olay Foaming Face Wash: Sensitive	no	n/a	4.99	6.78	
Olay Fresh Effects Clear Skin (Acne Hater Deep Scrub)	yes	polyethylene, polypropylene	6.49	5	"deep exfoliation"
Aveeno Clear Complexion Foaming Cleanser	no	n/a	7.99	6	
Aveeno Positively Radiant Brightening Cleanser	no	n/a	7.49	6	
Burt's Bees Sensitive Facial Cleanser w/ Cotton Extract	no	bark extract	9.99	6	99% natural
Burt's Bees Peach + Willowbark Deep Pore Scrub	no	ground peach stone, willow bark	7.99	4	99.9% natural, exfoliates
Burt's Bees Brightening Daily Facial Cleanser	no	n/a	9.99	6	98.7% natural
Burt's Bees Renewal Refining Cleanser	no	n/a	9.99	6	99% natural, gently exfoliates
Burt's Bees Natural Acne Solutions Pore Refining Scrub	no	willow bark, jojoba beads	9.99	4	99% natural
Burt's Bees Natural Acne Solutions Purifying Gel Cleanser	no	willow bark	9.99	5	99.4% natural
Burt's Bees Soap Bark + Chamomile Deep Cleansing Cream	no	peach stone, willow bark	8.99	6	99.9% natural
Burt's Bees Cleansing Oil	no	n/a	12.99	6	100% natural

Kinney Drugs: Canton, NY(Sampled February 26, 2015)

Product Name	**Microplastic Status**	**Exfoliating Agent**	**Price**	**OZ**	**Advertising Claims**
Happy Me Skin Care Natural Acne Wash	no	willow bark extract	8.49	8	gentle exfoliating
Olay Fresh Effects Clear Skin Acne Hater Deep Scrub	yes	polypropylene	7.49	5	deep exfoliation
Dr. Lin Skincare Daily Cleanser	no	n/a	7.49	8	
Premier Value Hydrating Cleanser	no	n/a	6.99	12	
Pan Oxyl Acne Foaming Wash	no	n/a	9.99	5	
Pan Oxyl Acne Cleansing Bar	no	n/a	7.29	4*	
Oxy 3-Way-Use Cleanser Daily Defense	no	n/a	7.99	5	scrub exfoliates
Oxy Rapid Treatment Face Wash Maximum Action	no	n/a	6.99	6.25	
Oxy Skin Clearing Soothing Cleanser Daily Defense	no	n/a	6.99	7	
Oxy Skin Clearing Brightening Cleanser Daily Defense	no	n/a	6.99	7	
Clean and Clear Morning Burst Facial Cleanser	no	mica, talc	6.69	8	bursting beads
Clean and Clear Morning Burst Facial Scrub	yes	polyethylene	6.69	5	scrubbing beads
Clean and Clear Advantage Acne Control 3-in-2 Foaming Wash	no	n/a	7.99	8	
Clean and Clear Advantage 3-in-2 Exfoliating Cleanser	yes	polyethylene	7.49	5	exfoliates skin
Clean and Clear Advantage Daily Soothing Acne Scrub	no	n/a	7.49	5	
Clean and Clear Continuous Control Acne Cleanser Daily	no	n/a	7.19	5	

Formula					
Clean and Clear Essentials Foaming Facial Cleanser	no	n/a	5.19	8	
Clean and Clear Deep Action Exfoliating Scrub	yes	polyethylene	5.99	5	exfoliating beads
Clean and Clear Deep Action Cream Cleanser	no	n/a	5.99	6.5	
Clean and Clear Blackhead Eraser Scrub	yes	polyethylene	5.99	5	gently exfoliates
Clean and Clear Daily Pore Cleanser	yes	polyethylene	5.99	5.5	gentle micro-scrubbers
Neutrogena Blackhead Eliminating Daily Scrub	yes	polyethylene	7.99	4.2	gentle exfoliating beads, microbeads
Neutrogena Oil-Free Acne Stress Control Power-Clear Scrub	yes	polyethylene	8.29	4.2	microbeads exfoliate
Neutrogena Oil-Free Acne Wash: Pink Grapefruit Facial Cleanser	no	n/a	8.49	6	
Neutrogena Oil-Free Acne Wash: Pink Grapefruit Foaming Scrub	yes	polyethylene	8.99	4.2	gentle microbeads
Neutrogena Naturals Acne Cream Cleanser	no	n/a	8.49	5	93% natural, Nature Conservancy endorsed
Neutrogena Naturals Acne Foaming Scrub	no	bark extract	8.49	4.2	93% natural, Nature Conservancy endorsed, exfoliating microbeads
Neutrogena: The Transparent Facial Bar	no	n/a	2.99	3.5*	
Neutrogena Oil-Free Acne Wash	no	n/a	7.49	6	
Neutrogena Oil-Free Acne Wash Cream Cleanser	no	n/a	7.79	6.7	
Neutrogena Oil-Free Acne Wash Daily Scrub	yes	polyethylene	7.79	4.2	microbeads
Neutrogena Deep Clean Cream Cleanser	no	n/a	6.29	7	
Neutrogena Deep Clean Gentle Scrub	yes	polyethylene	6.29	4.2	exfoliating microbeads
Neutrogena Deep Clean Invigorating Foaming Scrub	yes	polyethylene	8.49	4.2	energizing microbeads
Neutrogena Men Skin Clearing Acne Wash	no	n/a	5.99	5.1	
Neutrogena Clear Pore Cleanser/Mask	no	n/a	7.29	4.2	
Neutrogena Deep Clean Facial Cleanser	no	n/a	6.29	6.7	
Clearasil Daily Clear Refreshing Superfruit Wash	no	n/a	6.49	6.7	
Clearasil Ultra Rapid Action Daily Face Wash	no	n/a	7.69	6.78	
Clearasil Ultra Rapid Action Face Scrub	yes	polyethylene	7.69	5	exfoliating beads
Zapzyt Acne Wash Cleanser	no	n/a	5.99	6.25	
Zapzyt Pore Clearing Scrub	yes	synthetic wax	5.99	5	tiny microbeads, exfoliates
Biore Blemish Fighting Ice Cleanser	no	n/a	7.99	6.77	
Biore Deep Pore Charcoal Cleanser	no	charcoal	7.99	6.77	
Phisoderm Fragrance Free Cream Cleanser	no	n/a	4.99	6	
Olay Total Effects Revitalizing Foaming Cleanser	no	n/a	9.99	6.5	
Olay Regenerist Regenerating Cream Cleanser	yes	oxidized polyethylene	6.99	5	exfoliates, "oxygenated derma-beads"
L'OrealRevitalist Radiant	no	n/a	7.49	5	gentle exfoliating action

Smoothing Cream Cleanser					
Olay Regenerist Luminous Brightening Cream Cleanser	yes	polyethylene, petrolatum	9.49	5	"microbeads exfoliate"
Olay Age Defying Classic Cleanser	yes	oxidized polyethylene	4.99	6.78	
Aveeno Positively Radiant Brightening Cleanser	no	n/a	7.29	6.7	
Aveeno Positively Radiant Skin Brightening Daily Scrub	yes	polyethylene	7.29	5	gently exfoliates, microbeads
Aveeno Clear Complexion Foaming Cleanser	no	n/a	7.29	6	
Aveeno Ultra-Calming Foaming Cleanser	no	n/a	7.29	6	
Neutrogena Naturals Purifying Facial Cleanser	no	willow bark	7.99	6	90% natural, Nature Conservancy endorsed
Neutrogena Naturals Purifying Pore Scrub	no	jojoba beads	7.99	4	94% natural, Nature Conservancy endorsed
Neutrogena: The Transparent Facial Bar (Original Formula)	no	n/a	2.99	3.5*	
Alpha Hydrox Foaming Face Wash	no	n/a	8.49	6	
Simple Moisturizing Facial Wash	no	n/a	6.99	5	
Neutrogena Pore-Refining Exfoliating Cleanser	yes	polyethylene	8.49	6.7	gentle microbeads
Neutrogena Healthy Skin Anti-Wrinkle Anti-Blemish Cleanser	no	n/a	8.49	5.1	
Neutrogena Ultra Gentle Daily Cleanser Foaming Formula	no	n/a	9.49	12	
Neutrogena Fresh Foaming Cleanser	no	n/a	6.29	6.7	
Formula 10.0.6 So Totally Clean Deep Pore Cleanser	no	n/a	5.49	6.75	
Formula 10.0.6 Deep Down Detox Ultra-Cleansing Mud Mask	no	sea salt	5.49	3.4	
Formula 10.0.6 Best Face Forward Daily Foaming Cleasner	no	n/a	5.49	5	
L'Oreal Go 360 Clean Ideal Clean Deep Facial Cleanser for Sensitive Skin	no	scrublet pad	6.29	6	
L'Oreal Go 360 Clean Ideal Clean Anti-Breakout Facial Cleanser	no	scrublet pad	6.29	6	
L'Oreal Go 360 Clean Ideal Clean Deep Cleansing Exfoliating Scrub	yes	polyethylene, scrublet pad	6.29	6	
White Rain Gentle Facial Scrub	no	unknown	1.49	4	exfoliates
Pond's Luminous Clean Daily Exfoliating Cleanser	yes	white kaolin clay, oxidized polyethylene	6.29	5	gentle microbeads
Freeman HoneyDew and Chamomille Sleeping Mask	no	n/a	4.19	6	
Freeman Dead Sea Minerals Anti-Stress Mask	no	sea salt	4.19	6	
Freeman Charcoal and Black Sugar Polishing Mask	no	charcoal, black sugar	4.19	6	
Freeman Avocado and Oatmeal Clay Mask	no	oatmeal, kaolin clay	4.19	6	
Queen Helene Apricot Scrub	no	walnut shell, kaolin clay	2.99	6	gently exfoliates
Queen Helene Oatmeal n' Honey Scrub	no	oatmeal, walnut shell, kaolin clay	2.99	6	gently exfoliates
Queen Helene Mint Julep Masque	no	kaolin clay	2.99	8	
St. Ive's Nourished and Smooth Oatmeal Scrub + Mask	no	walnut shell, oatmeal	3.99	6	"100% natural exfoliants"
St. Ive's Blackhead Clearing Green Tea Scrub	no	n/a	3.99	6	"100% natural exfoliants"

St. Ive's Blemish Control Apricot Scrub	no	walnut shell, cornmeal	4.39	6	"100% natural exfoliants"
Premier Value Apricot Invigorating Scrub	no	walnut shell	2.99	6	exfoliates
Premier Value Medicated Apricot Scrub	no	walnut shell, willow bark	1.99	6	
Noxzema Classic Clean Original Deep Cleansing Cream	no	n/a	4.19	12*	
Noxzema Classic Clean Moisturizing Cleansing Cream	no	n/a	4.19	12*	
Noxzema Classic Clean Original Deep Cleansing Cream (fluid)	no	n/a	4.19	8	
SebaMed Liquid Face and Body Wash	no	n/a	12.99	13.5	
Cetaphil DermaControl Oil Control Foam Wash	no	n/a	12.99	8	
Petal Fresh Invigorating Aloe and Apricot Facial Scrub	no	walnut shell	3.99	7	
Cetaphil Daily Facial Cleanser	no	n/a	14.49	16	
Premier Value Gentle Skin Cleanser	no	n/a	6.99	16	
Cerave Foaming Facial Cleanser	no	n/a	13.99	12	
Yes To Tomatoes Clear Skin Acne Daily Pore Scrub	no	bamboo stem	10.49	4	97% natural
Yes To Cucumbers Soothing Sensitive Skin Gentle Milk Cleanser	no	n/a	9.49	6	98% natural
Yes To Carrots Nourishing Daily Cream Facial Cleanser	no	n/a	8.49	6	95% natural
Palmer's Cocoa Butter Formula Gentle Exfoliating Facial Scrub	no	crushed cocoa beans	8.49	5.25	"micro-fine cocoa beans"

Walmart: Potsdam, NY(Sampled February 26, 2015)

Product Name	Microplastic Status	Exfoliating Agent	Price	OZ	Advertising Claims
Burt's Bees Radiance Facial Cleanser with Royal Jelly	no	jojoba beads	9.97	6	99.2% natural
Equate Beauty Radiant Facial Cleanser with Royal Jelly	no	jojoba beads, sugar cane	6.98	6	
Burt's Bees Natural Acne Solutions Pore Refining Scrub	no	willow bark, jojoba beads	8.97	4	99% natural, exfoliates
Burt's Bees Natural Acne Solutions Purifying Gel Cleanser	no	willow bark	8.97	5	99.4% natural
Burt's Bees Sensitive Facial Cleanser w/ Cotton Extract	no	bark extract	8.76	6	99% natural
Equate Beauty Sensitive Facial Cleanser w/ Cotton Extract	no	bark extract, sugar cane, cotton, rice extract	6.95	6	
Burt's Bees Peach + Willowbark Deep Pore Scrub	no	ground peach stone, willow bark	7.82	4	99.9% natural, exfoliates
Yes To Carrots Nourishing Daily Cream Facial Cleanser	no	n/a	7.97	6	95% natural
Yes To Tomatoes Clear Skin Acne Daily Pore Scrub	no	bamboo stem	9.97	4	97% natural
Avalon Organics Intense Defense w/ Vitamin C Cleansing Gel	no	n/a	8.67	8.5	
Alba Botanica Hawaiian Facial Wash	no	n/a	9.97	8	
Alba Botanica Acne Dote Deep Pore Wash	no	willow bark extract	7.47	6	
Alba Botanica Acne Dote Face+Body	no	willow bark, walnut	7.47	8	

Scrub		shell			
Dial Oil-Free Acne Control Face Wash	no	n/a	3.97	7.5	
Clearasil Ultra 5 in 1 Exfoliating Wash	yes	polyethylene	7.97	6.78	"exfoliating wash"
Clearasil Ultra Rapid Action Gel Wash	no	n/a	6.97	6.78	
Clearasil Ultra Rapid Action Face Scrub	yes	polyethylene	6.97	5	"exfoliating beads"
Clearasil Ultra Rapid Action Daily Face Wash	no	n/a	6.97	6.78	
Clearasil Ultra Acne+MarksWash+Mask	no	n/a	6.97	6.78	
Clearasil Ultra Acne+Marks Daily Scrub	yes	polyethylene	6.97	5	"scrubbing beads"
Clearasil Daily Clear Hydra-Blast Oil-Free Face Wash	no	n/a	4.97	6.5	
Equate Beauty Oil-Free Daily Face Wash	no	n/a	2.77	6.5	
Oxy Sensitive Skin Rapid Treatment Face Wash Maximum Action	no	n/a	5.68	6.25	
Oxy Rapid Treatment Face Wash Maximum Action	no	n/a	5.68	6.25	
Neutrogena Oil-Free Acne Wash Daily Scrub	yes	polyethylene	5.47	4.2	gentle microbeads
Neutrogena Oil-Free Acne Wash Cream Cleanser	no	n/a	5.47	6.7	
Neutrogena: The Transparent Facial Bar (Acne-prone skin)	no	n/a	2.67	3.5*	
Neutrogena Oil-Free Acne Wash	no	n/a	6.47	9.1	
Equate Beauty Oil-Free Acne Wash	no	n/a	3.67	6	
Neutrogena Oil-Free Acne Wash Redness Soothing Cream Cleanser	no	n/a	6.97	7	
Neutrogena Oil-Free Acne Wash Redness Soothing Facial Cleanser	no	n/a	5.27	6	
Neutrogena Oil-Free Acne Wash: Pink Grapefruit Facial Cleanser	no	n/a	6.96	6	
Neutrogena Oil-Free Acne Wash: Pink Grapefruit Cream Cleanser	no	n/a	6.96	6	
Neutrogena Oil-Free Acne Wash: Pink Grapefruit Foaming Scrub	yes	polyethylene	6.96	4.2	gentle microbeads
Equate Beauty Pink Grapefruit Foaming Acne Scrub	unknown	mica, Candelilla wax (natural)	2.97	4.2	
Neutrogena Acne Stress Control Power-Clear Scrub	yes	polyethylene	6.97	4.2	"microbeads exfoliate"
Neutrogena Acne Stress Control Power-Clear Cream Wash	no	n/a	7.47	6	
Neutrogena All-in-1 Acne Control Daily Scrub	yes	polyethylene	7.47	4.2	"microbeads exfoliate"
Neutrogena Rapid Clear Foaming Scrub	yes	polyethylene	7.47	4.2	exfoliating microbeads
Neutrogena Rapid Clear Oil-Eliminating Foaming Cleanser	no	n/a	7.47	6	
Neutrogena Clear Pore Daily Scrub	yes	polyethylene	5.97	4.2	microbeads
Neutrogena Clear Pore Cleanser/Mask	no	n/a	5.97	4.2	
Neutrogena Blackhead Eliminating Daily Scrub	yes	polyethylene	5.97	4.2	gentle exfoliating beads, microbeads
Neutrogena Naturals Acne Foaming Scrub	no	bark extract	6.97	4.2	93% natural, Nature Conservancy endorsed, exfoliating microbeads
Clean and Clear Morning Burst Facial Cleanser	no	mica, talc	4.97	8	bursting beads
Equate Beauty AM Refreshing Facial Cleanser	no	n/a	3.47	8	"vitamin-enriched beads"

Clean and Clear Morning Burst Facial Scrub	yes	polyethylene	4.97	5	scrubbing beads
Clean and Clear Night-Releasing Deep Cleansing Face Wash	no	sea salt	5.47	8	
Clean and Clear Morning Burst Hydrating Facial Cleanser	no	mica	5.47	8	bursting beads
Clean and Clear Morning Burst Detoxifying Facial Cleanser	no	mica	5.47	8	bursting beads
Clean and Clear Morning Burst Shine Control Facial Cleanser	no	mica	5.47	8	bursting beads
Clean and Clear Morning Burst Skin-Brightening Facial Cleanser	no	mica	5.47	8	bursting beads
Clean and Clear Morning Burst Skin-Brightening Facial Scrub	yes	polyethylene	5.47	8	bursting beads, microbeads, exfoliates
Clean and Clear Essentials Foaming Facial Cleanser	no	n/a	3.97	8	
Clean and Clear Essentials Foaming Facial Cleanser Sensitive Skin	no	n/a	4.27	8	
Clean and Clear Advantage Acne Control 3-in-1 Foaming Wash	no	n/a	6.27	8	
Clean and Clear Advantage 3-in-1 Exfoliating Cleanser	yes	polyethylene, petrolatum	5.97	5	exfoliates
Clean and Clear Advantage Oil-Absorbing Cream Cleanser	no	n/a	5.97	5	
Clean and Clear Deep Action Cream Cleanser Sensitive Skin	no	n/a	5.27	6.5	
Clean and Clear Deep Action Exfoliating Scrub	yes	polyethylene	4.97	5	"exfoliating beads"
Equate Beauty Deep Clarifying Exfoliating Scrub Cleanser	unknown	micro-crystalline wax (petrolatum)	3.47	5	exfoliates, "tiny scrub ingredients"
Equate Beauty Blackhead Clearing Scrub	unknown	micro-crystalline wax (petrolatum); synthetic wax	2.97	5	exfoliates
Clean and Clear Blackhead Eraser Scrub	yes	polyethylene	4.97	5	exfoliates
Clean and Clear Continuous Control Acne Cleanser Daily Formula	no	n/a	5.27	5	
Equate Beauty Breakout Control Acne Cleanser	unknown	petrolatum	3.68	5	
Biore Deep Pore Charcoal Cleanser	no	charcoal	6.47	6.77	
Biore Pore Unclogging Scrub	yes	unknown	6.47	5	spherical beads
Biore Baking Soda Pore Cleanser	no	baking soda	6.44	6.77	exfoliates
Biore Blemish Fighting Ice Cleanser	no	n/a	6.47	6.77	
Biore Warming Anti-Blackhead Cleanser	no	n/a	6.47	4.5	
Benzac Acne Solutions Acne Eliminating Cleanser	no	n/a	9.94	6	
Neutrogena Rapid Clear Stubborn Acne Cleanser	no	n/a	8.47	5	
Acne Free Daily Skin Therapy Acne Wash	no	n/a	5.94	4.8	
Noxzema Classic Clean Original Deep Cleansing Cream	no	n/a	3.97	12*	
Noxzema Classic Clean Moisturizing Cleansing Cream	no	n/a	3.97	12*	
Noxema Ultimate Clear Anti-Blemish Daily Scrub	no	n/a	4.47	5	
Noxzema Classic Clean Original Deep Cleansing Cream (fluid)	no	n/a	3.97	8	
Noxema Ultimate Clear Daily Deep Pore Cleanser	no	n/a	3.97	6	

St. Ive's Nourished and Smooth Oatmeal Scrub + Mask	no	walnut shell, oatmeal	3.87	6	"100% natural exfoliants"
St. Ive's Even and Bright Pink Lemon and Mandarain Orange Scrub	no	n/a	3.87	6	"100% natural exfoliants"
St. Ive's Fresh Skin Apricot Scrub	no	apricot extract, cornmeal, walnut shell	3.87	6	"100% natural exfoliants"
St. Ive's Fresh Skin Apricot Cleanser	no	apricot extract, mica, cornmeal	3.87	6	"100% natural exfoliants"
St. Ive's Blemish Control Apricot Scrub	no	walnut shell, cornmeal	3.87	6	"100% natural exfoliants"
Equate Beauty Blemish Control Facial Scrub	no	walnut shell, cornmeal	1.97	6	"natural exfoliants"
Equate Beauty Refreshing Apricot Scrub	no	walnut shell, cornmeal	1.97	6	exfoliates
Simple Moisturizing Facial Wash	no	n/a	5.97	5	
Simple Smoothing Facial Scrub	no	n/a	5.97	5	"gently exfoliates"
Simple Foaming Cleanser	no	n/a	5.97	5	
Cerave Foaming Facial Cleanser	no	n/a	9.96	12	
Cetaphil Daily Facial Cleanser	no	n/a	10.43	16	
Equate Beauty Gentle Skin Cleanser	no	n/a	6.47	16	
Cetaphil DermaControl Oil Control Foam Wash	no	n/a	10.83	8	
Purpose Gentle Cleansing Bar	no	n/a	3.27	6*	
Purpose Gentle Cleansing Wash	no	n/a	4.67	6	
Basis Sensitive Skin Bar	no	n/a	1.97	4*	
Aveeno Active Naturals Smart Essentials Daily Detoxifying Scrub	yes	polyethylene, coconut, luffa	4.97	5	exfoliates
Aveeno Absolutely Ageless Nourishing Cleanser	no	n/a	7.97	5.2	
Aveeno Active Naturals Clear Complexion Foaming Cleanser	no	n/a	6.77	6	
Aveeno Active Naturals Clear Complexion Cream Cleanser	yes	polyethylene	6.77	5	exfoliates
Aveeno Positively Radiant Skin Brightening Daily Scrub	yes	polyethylene	6.77	5	gently exfoliates, microbeads
Aveeno Positively Radiant Skin Brightening Cleanser	no	mica	6.77	6.7	
Aveeno Active Naturals Ultra-Calming Foaming Cleanser	no	n/a	6.77	6	
e.l.f. Daily Face Cleanser	no	n/a	5	3.7	
e.l.f. Exfoliating Scrub	no	walnut shell	6	3.38	exfoliates
Garnier Clean Invigorating Daily Scrub	yes	polyethylene	5.97	6.8	
Garnier Skin Active Clean+ Shine Control Cleansing Gel	no	charcoal	5.97	8	
Garnier Skin Active Clean+ Blackhead Eliminating Scrub	yes	polyethylene, charcoal	5.97	5	microbeads
Garnier Skin Active Clean+ Pore Purifying 2-in-1 Clay Mask/Cleanser	no	kaolin clay, charcoal	5.97	5	
Garnier Clean+ Gentle Clarifying Cleansing Gel	no	n/a	5.97	8	
Garnier Clean+ Makeup Removing Lotion Cleanser	no	n/a	5.97	6.8	
Garnier Clean+ Balancing Daily Exfoliator	yes	polyethylene	5.97	6.8	"gel exfoliator"
Freeman Charcoal and Black Sugar Polishing Mask	no	charcoal, black sugar	3.27	6	
Freeman Avocado and Oatmeal Clay Mask	no	oatmeal, kaolin clay	3.27	6	
L'Oreal Go 360 Clean Ideal Clean Deep Cleansing Exfoliating Scrub	yes	polyethylene, scrublet pad	4.37	6	

L'Oreal Go 360 Clean Ideal Clean Deep Facial Cleanser for Sensitive Skin	no	scrublet pad	4.37	6	
Equate Beauty Mild Liquid Facial Soap	no	n/a	7.96	6.7	
ROC Max Resurfacing Facial Cleanser	yes	polyethylene	8.97	5	
L'OrealRevitalift Radiant Smoothing Cream Cleanser	no	n/a	5.97	5	"exfoliating"
L'Oreal Cream Cleanser Age Perfect Gentle Daily Cleanser	no	n/a	5.97	5	
Neutrogena Pore Refining Exfoliating Cleanser	yes	polyethylene	7.46	6.7	microbeads
Neutrogena Pore Refining Daily Cleanser	no	n/a	7.46	6.7	
Neutrogena Ultra Gentle Hydrating Cleanser Creamy Formula	no	n/a	8.74	12	
Neutrogena Ultra Gentle Daily Cleanser Foaming Formula	no	n/a	8.97	12	
Neutrogena: The Transparent Facial Bar (Original Formula)	no	n/a	1.97	3.5*	
Liquid Neutrogena: The Transparent Facial Cleanser	no	n/a	7.47	8	
Neutrogena Naturals Purifying Pore Scrub	no	jojoba beads	6.94	4	94% natural, Nature Conservancy endorsed
Neutrogena Naturals Purifying Cream Cleanser	no	willow bark, rice	6.94	5	98% natural, Nature Conservancy endorsed
Neutrogena Naturals Purifying Facial Cleanser	no	willow bark	6.94	6	90% natural, Nature Conservancy endorsed
Neutrogena Healthy Skin Boosters Facial Cleanser	no	n/a	7.47	9	
Neutrogena Deep Clean Long-Lasting Shine Control Daily Scrub	yes	polyethylene, rice	7.47	4.2	exfoliates
Neutrogena Deep Clean Long-Lasting Shine Control Cleanser/Mask	no	rice	7.47	6	
Neutrogena Deep Clean Invigorating Foaming Scrub	yes	polyethylene	6.97	4.2	energizing microbeads
Neutrogena Deep Clean Gentle Scrub	yes	polyethylene	5.24	4.2	exfoliating microbeads
Neutrogena Deep Clean Cream Cleanser	no	n/a	5.24	7	
Neutrogena Deep Clean Facial Cleanser	no	n/a	5.24	6.7	
Neutrogena Fresh Foaming Cleanser	no	n/a	5.24	6.7	
Equate Beauty Foaming 2-in-1 Cleanser	no	n/a	2.98	6.7	
Olay Professional ProfessionalProx Exfoliating Renewal Cleanser	yes	polyethylene	17.97	6	"microbead formula"
Olay Regenerist Luminous Brightening Cream Cleanser	yes	polyethylene, petrolatum	7.96	5	"microbeads exfoliate"
Olay Regenerist Luminous Brightening Foaming Cleanser	no	n/a	7.96	6.7	
Olay Regenerist Advanced Anti-Aging Detoxifying Pore Scrub Cleanser	yes	polyethylene	7.96	6.5	microbeads
Olay Regenerist Advanced Anti-Aging Regenerating Cream Cleanser	yes	oxygenated polyethylene	5.97	5	exfoliates, "oxygenated derma-beads"
Equate Beauty Regenerating Daily Cleanser	yes	polyethylene	3.97	5	"gently exfoliates"
Olay Age Defying Classic Cleanser	yes	oxidized polyethylene	4.67	6.78	
Equate Beauty Age-Resisting Classic Cleanser	yes	polyethylene	3.27	6.78	
Olay Total Effects Revitalizing Foaming Cleanser	no	n/a	7.96	6.5	

Olay Total Effects Nourishing Cream Cleanser	no	n/a	7.96	6.5	
Olay Total Effects Refreshing Citrus Scrub Cleanser	yes	oxidized polyethylene	7.96	6.5	
Olay Gentle Clean Foaming Cleanser	no	n/a	4.97	7	
Olay Cleanser+Scrub	yes	polyethylene	6.97	5	exfoliating
Olay Foaming Face Wash	no	n/a	4.97	7	
Burt's Bees Radiance Facial Cleanser with Royal Jelly	no	jojoba beads	9.97	6	99.2% natural
Equate Beauty Radiant Facial Cleanser with Royal Jelly	no	jojoba beads, sugar cane	6.98	6	
Burt's Bees Natural Acne Solutions Pore Refining Scrub	no	willow bark, jojoba beads	8.97	4	99% natural, exfoliates
Burt's Bees Natural Acne Solutions Purifying Gel Cleanser	no	willow bark	8.97	5	99.4% natural
Burt's Bees Sensitive Facial Cleanser w/ Cotton Extract	no	bark extract	8.76	6	99% natural
Equate Beauty Sensitive Facial Cleanser w/ Cotton Extract	no	bark extract, sugar cane, cotton, rice extract	6.95	6	
Burt's Bees Peach + Willowbark Deep Pore Scrub	no	ground peach stone, willow bark	7.82	4	99.9% natural, exfoliates
Yes To Carrots Nourishing Daily Cream Facial Cleanser	no	n/a	7.97	6	95% natural
Yes To Tomatoes Clear Skin Acne Daily Pore Scrub	no	bamboo stem	9.97	4	97% natural