A reprint from
American Scientist
the magazine of Sigma Xi, The Scientific Research Honor Society

Plastics, Plastics Everywhere

Studies in the Great Lakes and beyond highlight the ubiquity of microplastics in our rivers and drinking water.

Sherri A. Mason

I just want to say one word for you, just one word. . . . Plastics. In its time, this iconic line from *The Graduate* made a valid point: In 1967, there was a "great future in plastics." Since then plastics production has exploded, and in 2017 the world produced nearly 450 million metric tons of these lightweight materials, the equivalent of more than three million Olympic-sized swimming pools, used in everything from automobiles to food packaging to personal care products. Nearly two-thirds is discarded, whereas almost 10 percent is recycled and 12 percent is incinerated. As much as 15 percent ends up in our waterways each year.

Plastics weren't on my mind in 2011 when I first stepped aboard the U.S. brig *Niagara* to teach students about how atmospheric fallout contaminates the Great Lakes. By that time I had lived along the shores of Lake Erie—the smallest, shallowest, and warmest of the Great Lakes—for 10 years. But I had never been out on the lake, in part, because of the smell: Its often pungent shorelines were littered with decaying algae and dead fish.

Sherri "Sam" A. Mason's research group is among the first to study the prevalence and affect of plastic pollution within freshwater ecosystems. She received her PhD in chemistry from the University of Montana. She was an EPA Environmental Champion in 2016, received the Excellence in Environmental Research award from the Earth Month Network in 2017, and earned the Heinz Award in Public Policy in 2018. She is now sustainability coordinator at Penn State Behrend. Email: sam7201@psu.edu

But aboard the *Niagara,* on the open waters of the lake, I was dumbfounded. Lake Erie was vast and beautiful. The air was crisp; the sunlight glistened off the clean, blue waves. The shoreline was not even visible—that is how vast the Great Lakes are. On the *Niagara* during the following summer, undergraduate students and I began sampling the water for plastics as a teaching exercise. Before I knew it, my research changed course. I was studying plastics pollution.

The author has collected microplastics from the surface of all five Great Lakes, mostly aboard the U.S. brig *Niagara*. A replica of a ship that saw action during the Battle of Lake Erie in the War of 1812, the *Niagara* often sails the Great Lakes in the summer. At other times, she is typically docked behind the Erie Maritime Museum.

When we started, I expected to find large objects such as bags, straws, or bottles, but instead we mostly found small fragments, some of them too small to see. These plastic particles—tiny threads, fragments, or beads—are collectively known as microplastics.

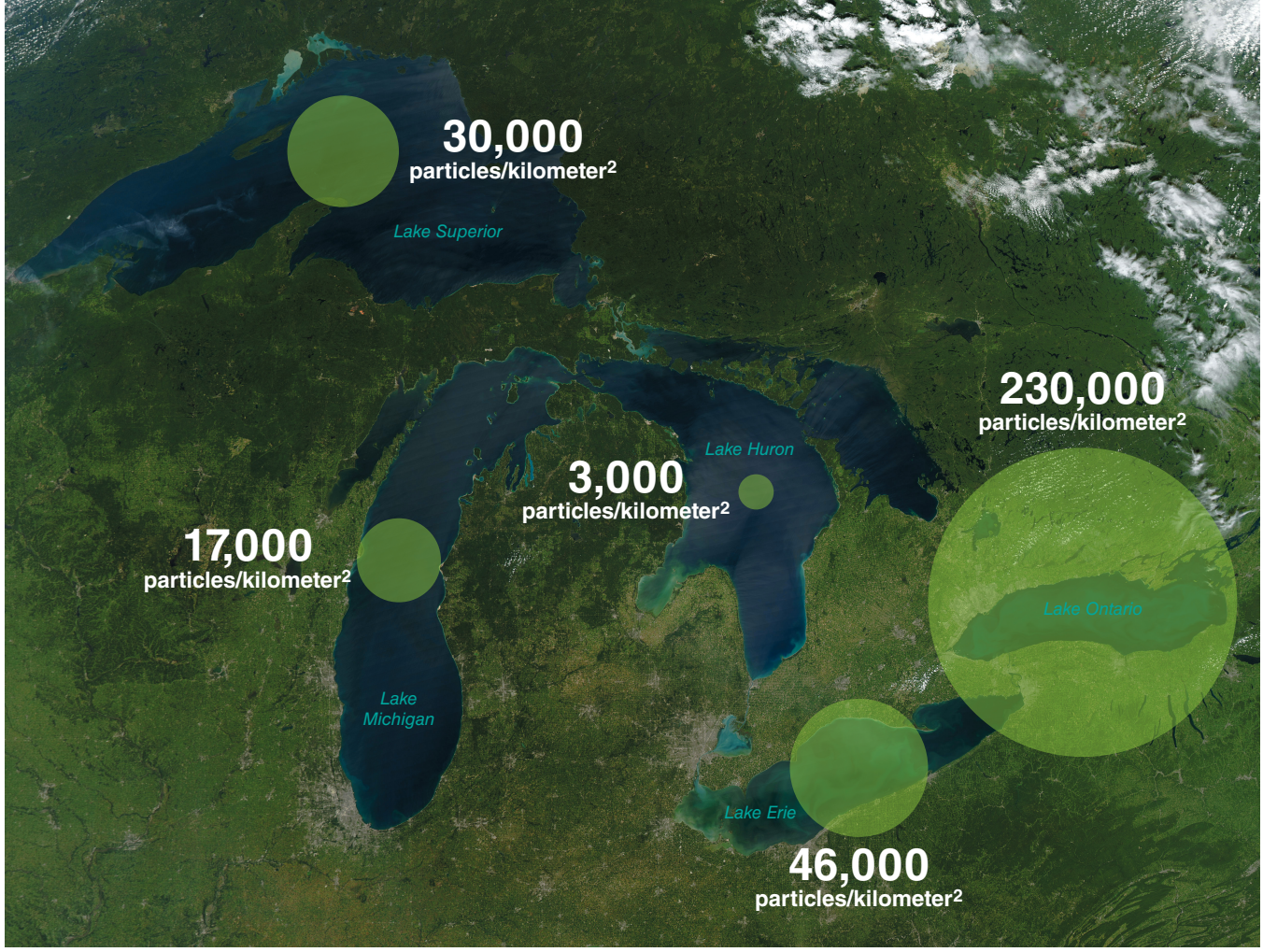
Over the next three years, I would sail, swim, and sample all five of the Great Lakes that collectively form the world's largest freshwater ecosystem. At that time, we already knew that plastics were polluting the oceans and that most ocean plastic was coming from land. Marine species can ingest plastics of all sizes, but these tiny particles also leach chemicals with known human health effects and provide a surface for collecting and concentrating other water pollutants (*see the graphic on page 286*). Researchers hypothesized that plastic traveled to the ocean through fresh water, and the Great Lakes seemed like the prime location to start looking. These five inland seas flow into one another with the waters ultimately gushing into the St. Lawrence River and out into the northern Atlantic Ocean.

In 2012 I started a series of eight expeditions, each with up to 20 undergraduate students, to quantify plastic pollution within the Great Lakes. Sailing on the *Niagara,* we used surface-skimming nets to collect anything larger than 0.3 millimeters. On board, we transferred those samples to containers. Back on land, in the laboratory, we would separate and remove tiny zooplankton, algae, plants, and bugs to reveal the microplastics.

Tiny Plastics in Wastewater

On an average day most of us take a shower and brush our teeth. Many of us use an exfoliating face wash, shampoo, or body wash. Before 2018, many of these products contained microbeads, small (approximately 0.33 millimeters in

Sherri A. Mason



The Great Lakes form a five-lake system that holds more than 20 percent of the world's surface fresh water. The largest, Lake Superior, flows into Lake Huron, which geologically forms a single lake with Lake Michigan, separated by the lower peninsula of Michigan. The primary outlet for Lake Huron is Lake Erie, which then gushes into Lake Ontario via Niagara Falls. All of this water moves into the St. Lawrence Seaway and eventually into the North Atlantic. In the map above, the numbers and bubble sizes demonstrate the average number of microplastic particles per square kilometer of surface water in each lake.

Barbara Aulicino; satellite image Jeff Schmaltz, MODIS Rapid Response Team/NASA/GSFC

diameter), round beads of plastic (usually polyethylene), included as a gentle abrasive. As the products are used, these microbeads are flushed down the drain with the wastewater. In an average week most of us also do laundry. As we clean our clothing, sheets, and towels, tiny threads—commonly called microfibers—break off and wash away. To better understand how microbeads and microfibers—collectively making up microplastics—move through the Great Lakes and other freshwater systems, we wanted to understand whether they are removed at wastewater treatment plants.

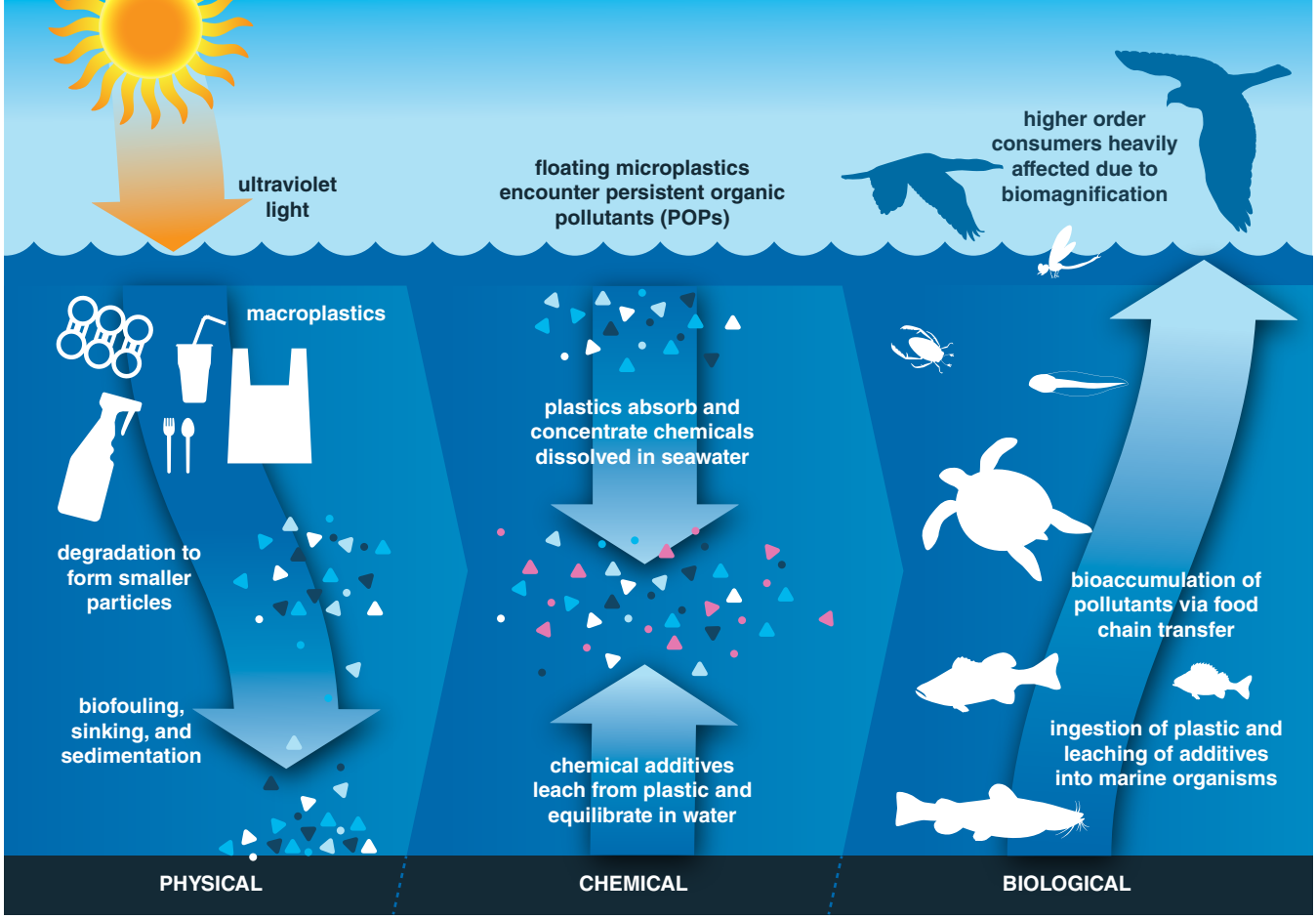
After collecting and analyzing 90 samples taken from 17 different facilities across the United States, we confirmed that microplastics travel through wastewater treatment plants. On average, each wastewater treatment facility was releasing more than four million pieces of microplastic into U.S. waterways every day: 60 percent fibers, 34 percent beads, and 6 percent films and foams. With 15,000 such facilities in continual operation around the United States, billions of microplastic particles are finding a pathway through our wastewater from our homes to the fresh water we rely on.

Most wastewater treatment plants discharge into streams and rivers, which eventually flow to lakes and other large bodies of water. Wastewater treatment plants were built to remove urine, fecal matter, nutrients, and microbes, which are known to have negative impacts on the environment and the organisms that rely on that water: They weren't designed to remove plastics. Other studies have shown that wastewater treatment plants can remove 75 to 99 percent of these microplastics from wastewater, depending on the study conditions and the particle sizes sampled. But even when removed from wastewater, microplastics remain in sewage sludge, which is often applied to agricultural land as a fertilizer. As a result, they stay in the ecosystem and through runoff can end up back in the lakes and oceans anyway.

A Great Lakes Perspective

Given our wastewater treatment plant study, one may think that such plants are a primary pathway of microplastics into our freshwater bodies. But when we studied 29 of the major tributaries to the Great Lakes—nearly one-quarter of the flow into these inland seas—we uncovered a different story.

These rivers span different land covers, wastewater effluent contributions, population densities, and hydrologic conditions. In our studies, urban runoff contributed significantly more to microplastic abundances than wastewater treatment plant effluent. In both wastewater and freshwater samples, microfibers were the most abundant microplastic type and did not seem to be correlated with either land use or hydrologic conditions. Other studies, including a 2019 study within the Pyrenees Mountains, highlight one explanation: the presence of microfibers in our air. Such tiny threads—



Plastics can have a range of physical, chemical, and environmental effects in fresh water. As the Sun's ultraviolet rays strike plastic objects such as bottles, bags, or straws, these objects break down into ever smaller fragments. These pieces foul water and sink into the sediments of lakes and streams. As microplastics move through waterways, they can leach chemical additives and sponge up persistent organic pollutants already present in the water. Aquatic life consumes microplastic particles, and these fragments and the chemicals within them accumulate in larger organisms and in humans.

from manufacturing clothes, drying laundry, and shedding in the environment—could account for the ubiquitous microfiber concentrations found in our river samples.

These 29 tributaries flow directly into the Great Lakes. This ecosystem starts in Lake Superior, the largest, most remote, and least densely populated of all five of the Great Lakes. But despite its relative remoteness, we found evidence of plastic pollution in all 187 samples we collected for a 2014 study. Although few people live around Lake Superior, water can linger for nearly 200 years, allowing plastic concentrations to build up over time. Our study projects that the lake's surface has an average of more than 30,000 particles per square kilometer, or 2.5 billion particles in total.

Despite this staggering number, Lake Superior is second to Lake Ontario, which appears to carry the greatest total load of plastic particles among the Great Lakes, with nearly 4.5 billion (*see map*). Because Lake Ontario is the last lake within the Great Lakes chain, it is not surprising that it has the greatest concentration of plastic pollution.

The plastic we use ultimately comes back to us in the food we eat and water we drink.

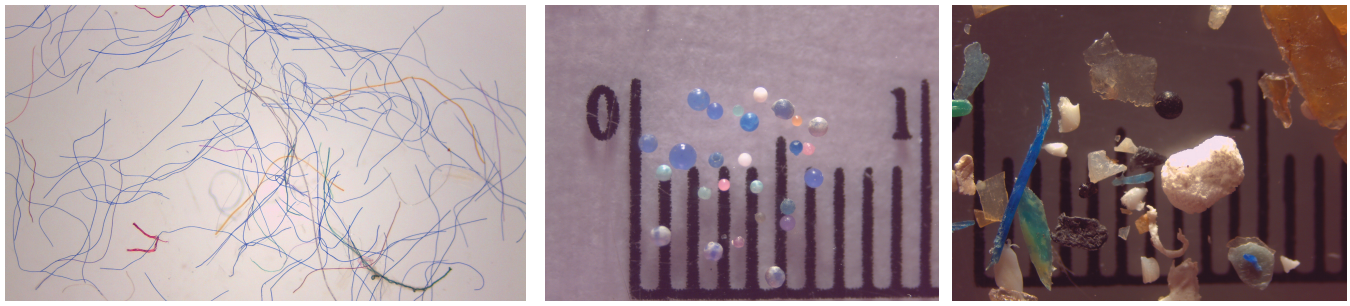
As plastic particles travel from our homes into and through wastewater treatment facilities, only to be added to those particles washing off our streets directly into our rivers, they all flow into larger bodies of water. Although the majority of my studies have focused on the Great Lakes, this story is the same across the United States and around the world. Further, the flow of wastewater from river to lake should remind each of us of one simple fact: We are all downstream from somewhere, and we are all upstream from the oceans that we share. Water ultimately and intimately connects us all to one another.

A Global View

Lakes, rivers, and streams represent the primary source of fresh water (approximately 70 percent) for all types of use. Because we find plastic pollution within fresh water throughout the planet, it's not surprising that we find it in our tap water. In 2017 we examined 159 samples of tap water collected from 14 different countries. Eighty-eight percent of these samples showed evidence of microplastic contamination, with an average of 5.5 particles per liter. Almost all (98 percent) of these particles were microfibers, which suggests that air is the primary source of contamination.

The overall health effects of these microplastics remain unknown. Research clearly shows that larger plastic debris harms more than 300 oceanic species. But teasing apart the potential chemical effects remains tricky. Plastic materials contain more than the polymer chains that give them structure; anywhere from 30 to 70 percent of their mass comes from colorants, plas-

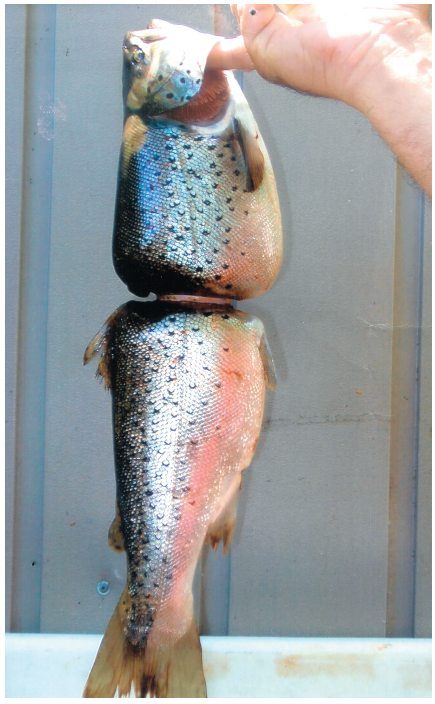
Barbara Aulicino



Microplastics in fresh water come in a variety of shapes and sizes. Microfibers (*left*) were the most abundant type found in the author's 2016 Great Lakes tributary study. Before passage of the Microbead-Free Waters Act of 2015, tiny plastic beads (*center*) were routinely added to many personal care products in the United States. A freshwater sample can include particles in many forms: foams, pellets, fragments, lines, and films (*right*).

ticizers, and other chemicals, some of which can act as endocrine disrupters or have been linked with cancer, obesity, and more. The chemicals found in plastics have been found in human tissues, but it's unclear whether we're ingesting those chemicals from plastic, food, or other sources.

When we released these findings in 2017, I expected that people would be so shocked that plastics contaminate tap water that they would demand change. But as I answered questions from the media and the public, I soon realized that people cited our work as an argument for drinking bottled water. This conclusion didn't make sense to us, and we immediately shifted to studying bottled water around the world.



Sherri A. Mason; Jim Bodenstab

Plastic waste has both dramatic and less obvious effects on fish and other aquatic life. Although this image depicts the obvious harm of plastic trash, much smaller particles and any associated chemicals also accumulate in such animals from the waters and from eating other organisms.

In our bottled water study, we analyzed 11 top-selling brands of bottled water—259 individual bottles purchased in 19 locations within nine different countries. All the brands and 93 percent of the individual bottles showed evidence of microplastic contamination. Per unit volume, we found twice as many plastic particles of similar size in bottled water as in tap water. However, in this study we could measure much smaller particle sizes (6.5 micrometers in bottled water versus 100 micrometers in tap water). When you consider this smaller size fraction, we found an average of 325 particles of plastic per liter of bottled water as compared with 5.5 microparticles in tap water. Furthermore, given the particle shapes (largely fragments, rather than fibers) and the chemical makeup (largely polypropylene), these data show that the majority of these plastics came from the bottling process.

Drinking water isn't the only source from which people are ingesting microplastics. We have also found particles in beer, sea salt, and freshwater (game) fish.

These more recent studies show us something very basic: that age-old adage that what goes around, comes around. The plastic we use ultimately comes back to us in the food we eat and the water we drink. Although this is scary and a bit distressing, it also means we can make positive changes.

After our first Great Lakes study in 2013, New York state proposed legislation limiting the use of microplastics in personal care products. As our work received increasing press coverage and plastic pollution groups boosted public awareness, I was asked to testify before numerous policy boards and committees. Meanwhile, consumers demanded loudly and consistently that they didn't want microbeads in their face wash, body wash, shampoos, and toothpastes. In 2015, the U.S. Congress unanimously passed the Microbead-Free Waters Act of 2015. Although this legislation is not expected to rein in pollution from plastic microfibers, it is a major success story in the work toward reducing microplastics in the environment.

As a next step, our society needs to reduce overall plastic production and consumption, because plastic materials of all sizes can pollute and degrade into ever smaller particles. Each of us can reduce our individual use of plastic, lobby industry to use alternative materials and package products within reusable containers, and push our governments to enact legislation in the best interest of public health. This success highlights hope for the future, characterized by a quote from Margaret Mead: "*Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has.*"

References

Baldwin, A. K., S. R. Corsi, and S. A. Mason. 2016. Plastic debris in 29 Great Lakes tributaries: Relations to watershed attributes and hydrology. *Environmental Science & Technology* 50:10377.

Mason, S. A., et al. 2016. Pelagic plastic pollution within the surface waters of Lake Michigan, U.S.A. *Journal of Great Lakes Research* 42:753–759.

Mason, S. A., V. G. Welch, and J. Neratko. 2018. Synthetic polymer contamination in bottled water. *Frontiers in Chemistry* 6:407. doi: 10.3389/fchem.2018.00407

Eriksen, M., et al. 2013. Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Marine Pollution Bulletin* 77:177–182.

Mason, S. A., et al. 2016. Microplastic pollution is widely detected in U.S. municipal wastewater treatment plant effluent. *Environmental Pollution* 218:1045–1054.