SAN FRANCISCO BAY
MICROPLASTICS PROJECT

Science-Supported Solutions and Policy Recommendations

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EXECUTIVE SUMMARY

Plastics in our waterways and in the ocean, and more specifically microplastics (plastic particles less than 5 mm in size), have gained global attention as a pervasive and preventable threat to marine ecosystem health. The San Francisco Bay Microplastics Project was designed to provide critical data on microplastics in the Bay Area. The project also engaged multiple stakeholders in both science and policy discussions. Finally, the project was designed to generate scientifically supported regional and statewide policy recommendations for solutions to plastic pollution.

San Francisco Bay from Angel Island • Photo by Shira Bezalel, SFEI

The following ten recommendations were identified:

Policy

1. Support policies that reduce single-use plastics in the Bay Area and statewide;
2. Support the development of a San Francisco Bay Microplastics Management Strategy to reduce microplastics;
3. Increase collaboration on plastic pollution reduction efforts;

Infrastructure & Innovation

4. Identify and prioritize intervention points for microfibers around filtration;
5. Explore green stormwater infrastructure management options to reduce microplastics from entering San Francisco Bay;
6. Support innovation to address microplastic pollution in San Francisco Bay;

Research

7. Encourage textile industry to standardize methods to understand microfiber shedding;
8. Better identify microplastic sources and pathways in stormwater systems;
9. Support microplastic research to monitor impacts in the region over time; and

Education

10. Educate consumers, including the youth, on ways individuals can reduce microfibers from entering San Francisco Bay.

Surface water sample • Photo by Carolynn Box, 5 Gyres

1 An introduction to the PLASTIC POLLUTION MOVEMENT

Plastic pollution has recently become an issue of global concern, with multinational corporations making plastic waste reduction commitments, and cities, states, and entire nations introducing increasingly comprehensive legislation to address single-use plastics, often referred to as "disposable" plastics, including plastic items intended to be used only once before they are thrown away or recycled. Single-use plastic items include bags, water bottles, straws, utensils, cups, and many forms of plastic packaging. Plastic pollution has gained worldwide attention through numerous scientific efforts that support a movement to reduce plastic pollution, and a series of legislative actions to address disposable plastics in communities around the world.

The 5 Gyres Institute (5 Gyres) published the first global estimate on micro- and macroplastics[1] in the world's ocean, estimating that 5.25 trillion pieces of microplastics, weighing over 250,000 tons, are floating on the ocean surface (Eriksen et al., 2014). Additional research has confirmed and further defined the issue of plastic pollution, demonstrating that a significant amount of microplastics enter the ocean from land (Jambeck et al., 2015).

As a result, community and environmental advocacy organizations have focused their efforts further upstream, aiming to prevent plastic pollution from entering water bodies and the ocean. San Francisco implemented the first plastic bag ban in 2007. Across the United States, there are hundreds of citywide plastic bag bans,[2] with California being the first to pass a statewide ban in 2014. New York and Hawaii have recently passed statewide legislation as well.

California has also led efforts to reduce microplastic pollution. While not the first state to ban personal care products with microbeads (tiny plastic spheres intentionally added to products for their abrasiveness and other purposes), California's 2015 ban was the most comprehensive. The ban was informed both by 5 Gyres' research on microplastics in the Great Lakes (Eriksen et al., 2013) and by a study that identified microbeads in San Francisco Bay (Sutton et al., 2016). President Barack Obama signed the Federal Microbead-Free Waters Act of 2015 banning plastic microbeads in rinse-off personal care products in the United States, which was fully effective as of July 2019. More information about plastic pollution policies can be found in Appendix A.

These local, state, and federal policies are now being challenged by an effort led by the American Legislative Exchange Council (ALEC)[3] to pass "pre-emption bills" in states across the country, preventing municipalities from passing bans or fees on plastic

1 plastic pieces smaller and larger than 5 mm in size, respectively
2 https://www.surfrider.org/pages/plastic-bag-bans-fees
3 https://www.alec.org/ (industry funded organization that advances corporate interests by driving conservative legislation across the US)

containers. Known as the "ban on bans", pre-emption legislation is now active in at least 12 states across the country, preventing all cities in these states from passing any ordinances that limit "auxiliary containers" (i.e., single-use plastic bags, bottles, takeout containers, etc.). If enacted, these ALEC-sponsored policies will prevent communities from addressing key waste concerns in their own neighborhoods.

The San Francisco Bay Microplastics Project is the first comprehensive effort to evaluate microplastics in an urban estuary. It was designed to:

- Assess and develop field and laboratory methods to measure microplastics across a variety of sample types;
- Synthesize the results to provide a baseline and evaluate factors influencing microplastic pollution;
- Prepare educational and outreach materials; and
- Provide data and stakeholder dialogue to inform policy change.

The project brought together stakeholders to collectively evaluate the research and to identify and discuss solutions.

Plastic debris near shore, Alameda, during king tide • Photo by Shira Bezalel, SFEI

What are microplastics, microparticles, and microfibers?

Microplastics are plastic particles smaller than 5 mm. In contrast, the term microparticles is used for particles smaller than 5 mm that appear to be plastic.

For this report, microplastics are a subset of microparticles for which spectroscopy or another technique has been used to verify that they are, in fact, plastic. Many of the microparticles extracted from samples collected for the San Francisco Bay Microplastic study could not be confirmed as plastic, either because they were not examined via spectroscopy due to resource constraints, or because the presence of a chemical such as a dye prevented identification of polymer type.

Microparticles and microplastics can be classified into five different shape categories, which can provide insight on sources:

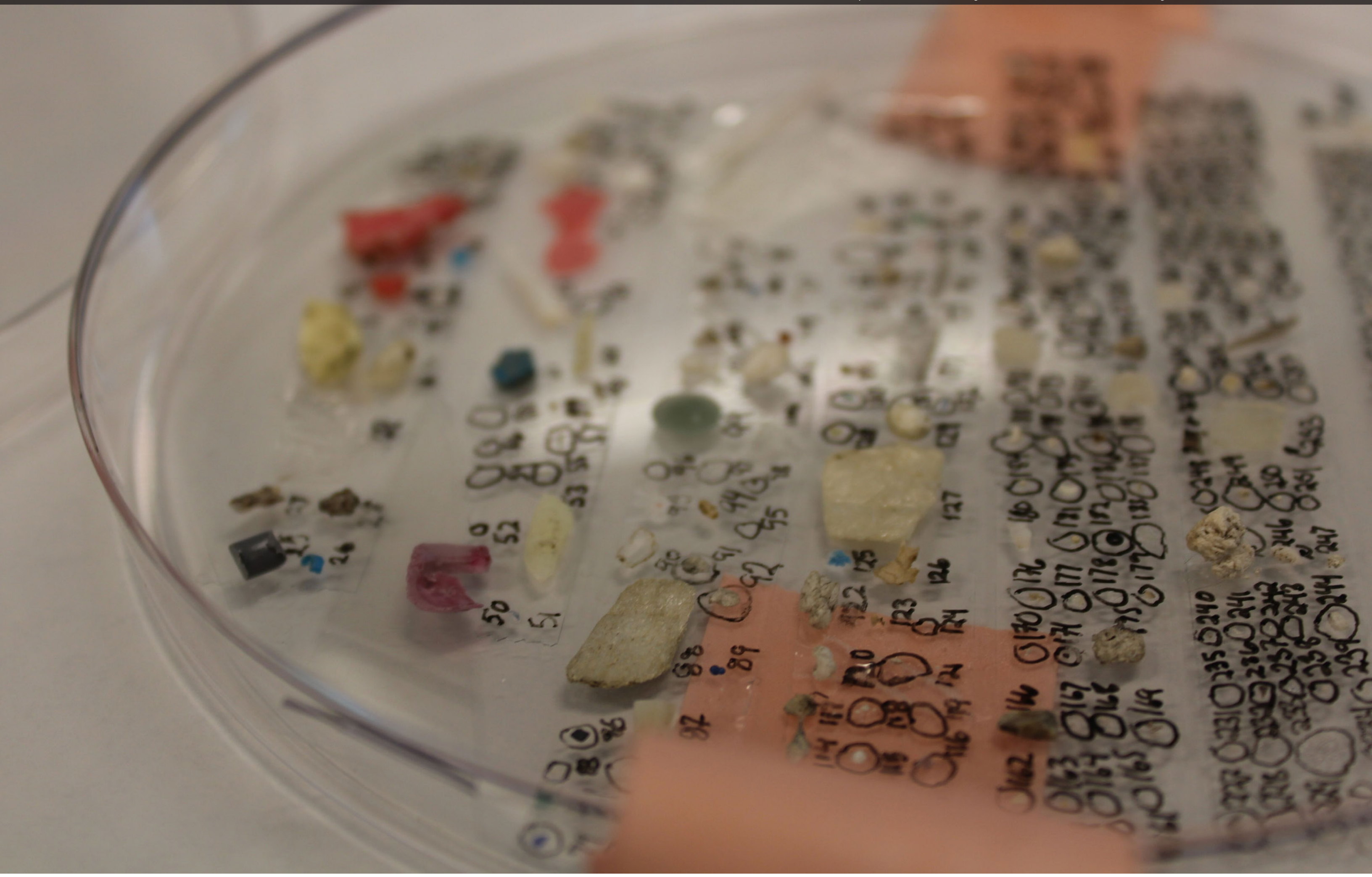
- Fragment – firm, jagged particle; may come from the degradation of larger plastic debris;
- Sphere or Pellet – hard, rounded, or spherical particle; may come from nurdles (pelletized pre-production material for plastic) or microbeads intentionally added to consumer products;
- Film – thin plane of flimsy material; may come from the degradation of film-like plastic debris, such as plastic bags and wraps;
- Foam – lightweight, sponge-like particle; may come from breakdown of foam plastic debris; and
- Fiber – thin or fibrous, straight particle; may come from textiles as well as fishing gear and cigarette filters; may form a tangled "fiber bundle" in the environment;

Microfibers refers to anthropogenic fibers (thin or fibrous particles) that are smaller than 5 mm, composed of synthetic (e.g., polyester, acrylic) or natural (e.g., cotton, wool) material, and end up in the natural environment as pollution. Plastic microfibers are synthetic and made of plastic.

Synthetic fibers have been used to produce textiles and fabrics for more than 50 years (Geyer et al., 2017) and easily shed during use, washing, and drying, entering the environment as plastic microfibers (Browne et al., 2011). Plastic microfibers may also be derived from fishing line and cigarette filters, among other products, as they degrade. During this study, stakeholders identified the need for better alignment of plastic microfiber terminology and definitions, particularly in light of existing technical definitions used by the textile industry.

Microplastics, including plastic microfibers, are chemically diverse contaminants made up of a variety of polymers including: polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET or polyester), acrylic, cellulose acetate, and nylon. Rubber is also considered plastic; in the San Francisco Bay Microplastic study, the rubber category included both natural (isoprene) and synthetic (styrene butadiene) rubbers (Sutton et al., 2019).

Surface water sample • Photo by Alice Zhu, University of Toronto



Why are microplastics a potential threat?

Microplastics have gained global attention as a pervasive and preventable threat to marine ecosystem health. They can be derived from any plastic product. They are a ubiquitous pollutant and have been detected globally in air, soil, and both fresh and saltwater, and from the sea surface to the ocean floor. They have been found in animals, as well as the food we eat and the water we drink.

With current plastics use, microplastics are continuously produced, whether intentionally or unintentionally, and escape into the environment. Approximately 9% of plastic ever generated has been recycled, whereas almost 80% has accumulated in landfills or the natural environment (Geyer et al., 2017). Globally, five to 13 million tons of plastic are estimated to enter the ocean every year (Jambeck et al., 2015). Plastics detected in the North Pacific Gyre have doubled in concentration in the last decade (Lebreton et al., 2018). Plastic production is only expected to further increase. Future projections indicate that annual production is likely to double to 600 million tons by 2030 (Azoulay et al., 2019).

Plastics do not biodegrade, but instead breakdown, fragmenting into smaller and smaller particles and persist in the environment. Microplastics are ingested by aquatic organisms and can adversely impact their health, although the exact mechanisms are not well understood. The diversity of microplastics (e.g., size, shape, and chemical composition) also makes microplastic toxicity difficult to predict, or even to study, as each type of microplastic may cause different effects and have a different toxicity threshold.

Microplastics frequently contain harmful chemical additives such as flame retardants or plasticizers. Additionally, they may provide a substrate for the adsorption of other harmful chemicals in the ocean, including polychlorinated biphenyls or pesticides (Browne et al., 2011; Teuten et al., 2007). Once ingested, these contaminants can be concentrated up the food chain (Rochman et al., 2014).

While toxicological evaluation of the impacts of microplastic pollution on wildlife is ongoing, and considerable uncertainties remain, a recent comprehensive European Union analysis of microplastics proposes considering any amount released into the environment as potentially harmful because of their persistence, difficulty of removal, and unknown toxic thresholds.[4] The ongoing efforts in the EU to classify microplastics as a “non-threshold contaminant” is a reflection of the potential risks to wildlife, humans, and our ecosystems.

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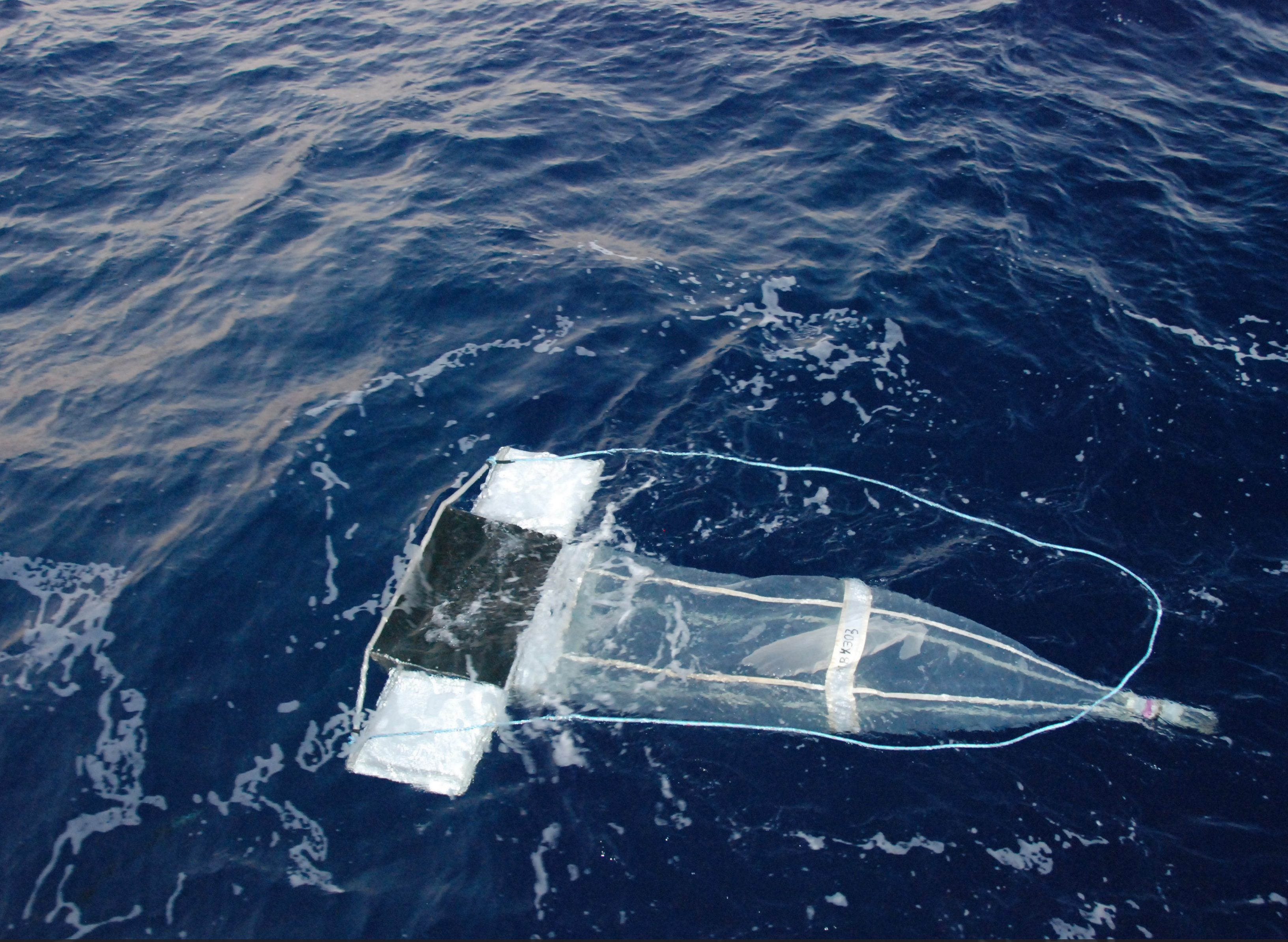
4 https://ec.europa.eu/research/sam/pdf/topics/microplastic-sam_workshop-012019.pdf



Plastic particles collected by a manta net in the North Pacific Gyre • Photo courtesy of NOAA (Creative Commons)

Bottlecaps collected at the Midway Atoll • Photo courtesy of NOAA (Creative Commons)

What are the pathways and sources of microplastics?

Many microplastic particles started out as larger plastic items, often single-use plastic items. These items can escape waste management infrastructure and end up in the environment, where they break into smaller pieces when exposed to UV light, heat, and mechanical abrasion (e.g., caused by waves). Some common plastic polymers in single-use items include polyethylene (plastic bags, plastic utensils), polypropylene (plastic tubs and food containers), polystyrene (expanded to form a foam used in coffee cups, coolers, and packing materials), polyethylene terephthalate (plastic water bottles), cellulose acetate (cigarette filters), and rubber (vehicle tires).

The majority of microparticles identified in the project were microfibers that can be derived from several sources (**Table 1**). Common plastic polymers used in synthetic textiles include polyester (also known as polyethylene terephthalate or PET), acrylic, nylon, and cellulose acetate. It is important to note that while much attention has focused on the clothing industry, the science isn't clear on the primary sources of microfibers. For example, carpets and other household textiles (bedding, sheets, upholstery, towels, etc.) may also be significant contributors.

Microfibers can enter the Bay through various pathways, including wastewater, stormwater, and air deposition. **Figure 1** identifies the general pathways for microplastics in the San Francisco Bay Area.

Discarded tires in San Francisco Bay • Photo by Shira Bezalel, SFEI

Table 1. Potential Pathways and Sources for Plastic Microfibers to the ocean

Environmental Compartments	Potential Pathways	Potential Sources
Wastewater / effluent	Washing machines (institutional, commercial, and residential), household and industrial drains (bathroom and kitchen), sewer, industrial discharge	Textiles (including clothing, bedding and towels, carpets, upholstery), baby wipes, personal care products, diapers, tampons, many more
Stormwater	Industrial discharge, storm drains, road runoff, agricultural runoff, precipitation, road abrasion	Plastic industry manufacturers (nurdles, plastic packaging and textiles), cigarette filters, fertilizers, biosolids disposal, airborne microplastics, astroturf, road abrasion, many others
Airborne	Urban dust, wind	Textiles (including fibers released by dryer vents and during wear), many more
Ocean and bay surface waters / sediment / fish and other marine species	All of the above	All of the above; marine industry (fishing line, sails, tarps, nets, synthetic ropes, etc.)

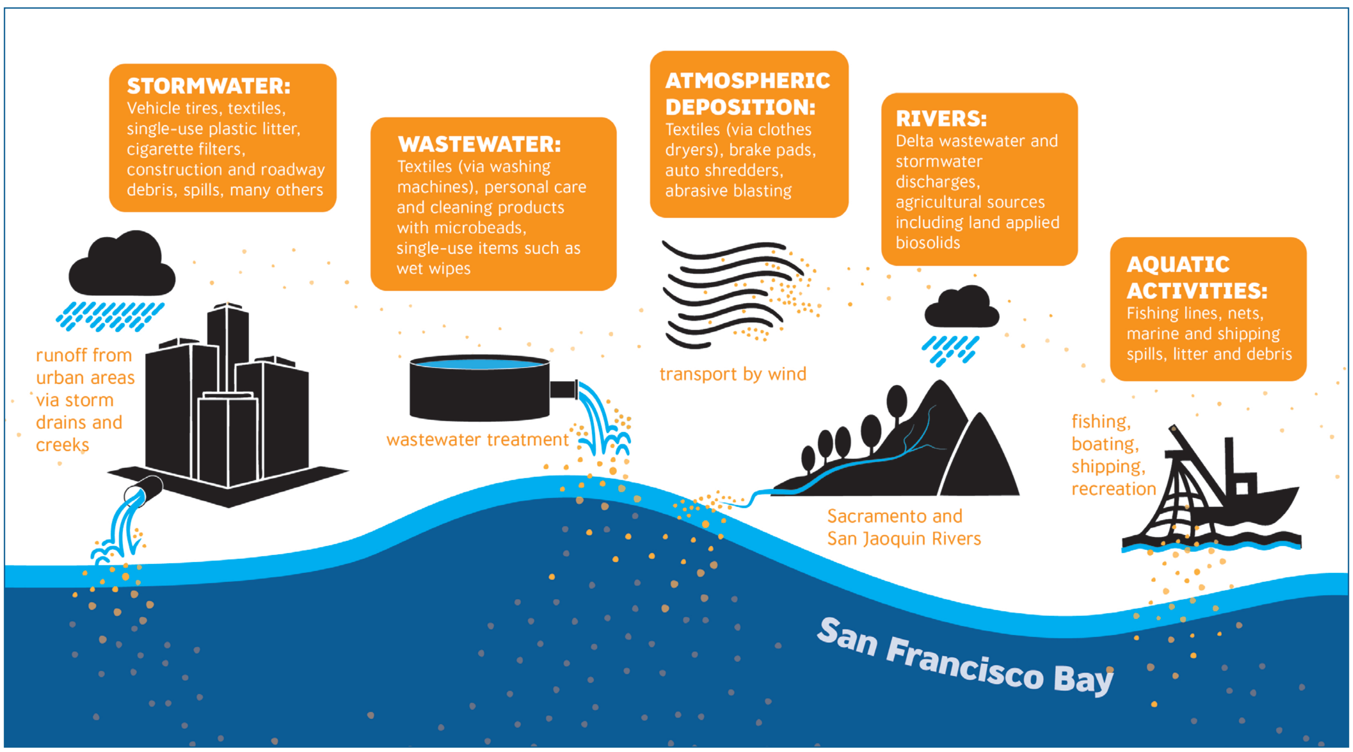


Figure 1. Potential pathways and sources for microplastics in San Francisco Bay. From Sutton et al, 2019 (Illustration by Katie McKnight)

Sampling using the manta trawl in norther San Francisco Bay • Photo by Erika Delemarre

Other microplastics are released directly into the environment in their original form. These "primary microplastics" include pre-production plastics, often in the form of pellets (i.e., "nurdles") and plastic powders used in plumbing and agriculture. These pre-production plastics can enter the environment through spillage or shipping accidents.

Another form of primary microplastics are microbeads, small pellets and fragments added to personal care products such as facial/body scrubs and toothpaste. Common polymers used to make microbeads include polyethylene and polypropylene. Primary microplastics are also used in a variety of industrial activities, such as fluids used in oil and gas drilling, water purification, abrasives used during airblasting to remove paint from boat surfaces and in cleaning engines and metal surfaces.

2 USING SCIENCE TO INFORM ACTION

Together, 5 Gyres and the San Francisco Estuary Institute (SFEI) have worked in partnership on the San Francisco Bay Microplastics Project to generate the science and data to inform recommendations for plastic pollution solutions in the San Francisco Bay and beyond.

Additional support was provided by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP), which provides scientific information that regulators and decision-makers need to manage the Bay effectively. The RMP is an innovative collaborative effort among SFEI, the Regional Water Quality Control Board, and stormwater and wastewater discharger communities, among others. The RMP has established a Microplastic Science and Monitoring Strategy for San Francisco Bay outlining the priority scientific information needs for the Bay (Sutton and Sedlak, 2017). The RMP also supports a Microplastics Workgroup, which serves as a forum for scientific discussion among experts and regional and state stakeholders.

The San Francisco Bay Microplastics Project was developed to respond to the scientific needs identified by the RMP, and designed to provide critical research on microplastics in the Bay Area, generate scientifically supported, regional recommendations for solutions, and engage multiple stakeholders in the process. Understanding this issue

Launching manta trawl during surface water sampling • Photo by Erika Delemarre

from a scientific perspective is critical to inform and support effective policy solutions and innovations at numerous intervention points, including waste treatment, industry design, and individual/consumer behavior.

Development of this report

This report, prepared by 5 Gyres with input from SFEI and the project's Policy Advisory Committee, is based on existing science, science generated by the San Francisco Bay Microplastics Project, and related policy documents. The Policy Advisory Committee was made up of experts, policy makers, scientists, industry leaders, and environmental advocates selected to provide science-based recommendations on plastic pollution reduction (See Table A-1 in Appendix A). The Policy Advisory Committee convened two in-person meetings on December 13, 2018 and March 5, 2019 to discuss preliminary results, policy recommendations, and innovative solutions to the issue of plastic pollution.

5 Gyres has ten years of expertise in scientific research and engagement on the issue of plastic pollution. Since 2009, 5 Gyres has completed 19 expeditions, bringing over 300 citizen scientists on oceanic expeditions to witness and conduct research on marine plastic pollution. One of 5 Gyres' highest priorities has been disseminating science to a range of communities to engage them in solutions through local and national campaigns.

SFEI is one of California's premier aquatic and ecosystem science institutes. SFEI's mission is to provide scientific support and tools for decision-making and communication through collaborative efforts. SFEI provides independent science to assess and improve the health of San Francisco Bay, the California Delta and beyond, empowering government, civic, and business leaders to create cost-effective solutions for complex environmental issues.

Use of this report

Many of the recommendations of this report focus on regional policy efforts that emphasize the importance of source reduction. In addition, innovations along with individual actions are also summarized. Non-governmental organizations (NGOs), policymakers, companies, and scientists can use this document as a case study for engaging regional stakeholders in scientific studies and collaborative dialogue to generate microplastic pollution solutions. The document can also serve as a resource to inspire individuals and coalitions around the globe to address microplastics.

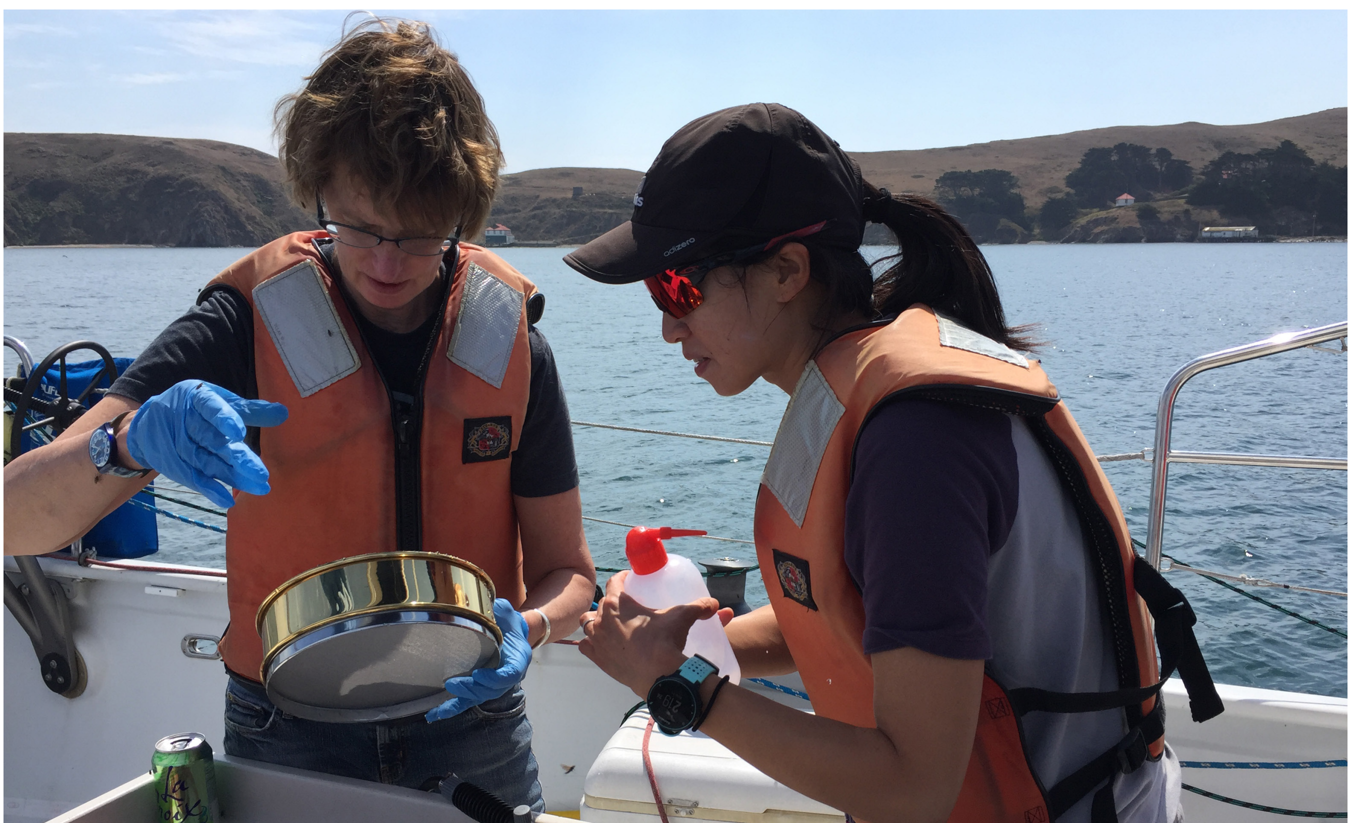
San Francisco Bay

3 MICROPLASTICS PROJECT FINDINGS

5 Gyres and SFEI conducted the first comprehensive study of microplastic pollution of a major estuary and adjacent National Marine Sanctuaries. This project supported multiple scientific components to develop improved knowledge about and characterization of microparticles and microplastics in the San Francisco Bay Area. Below we have highlighted major findings from the project's scientific report (Sutton et al., 2019).

Rainy weather washes microplastics into Bay waters

To quantify the levels and composition of microparticles and microplastics in surface water, samples were collected during wet and dry seasons at 17 monitoring sites throughout San Francisco Bay and 11 monitoring sites within the adjacent National Marine Sanctuaries (Monterey Bay, Cordell Bank, and Greater Farallones).



Sample collection in San Francisco Bay • Photo by Carolynn Box, 5 Gyres

Microparticles were identified in all samples, with abundances generally higher in the Bay than the marine sanctuaries.

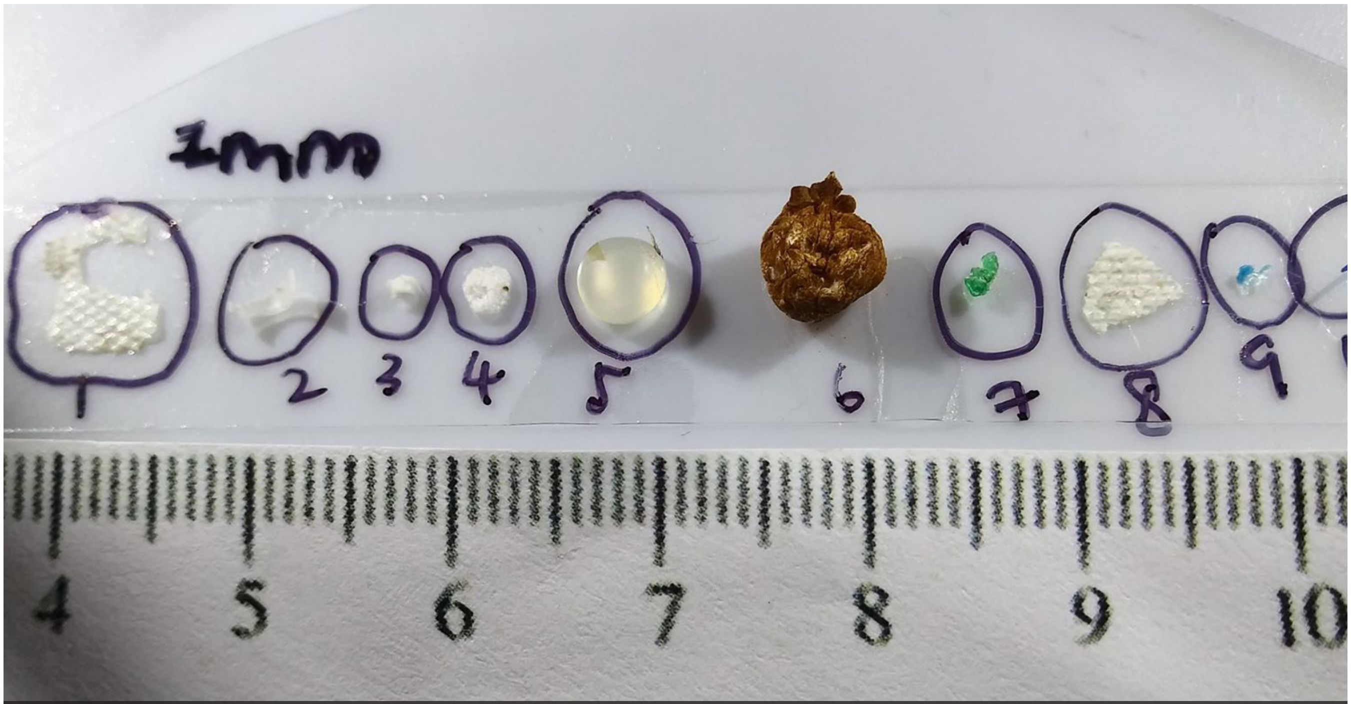
Following rainstorms, levels of microparticles and microplastics in Bay surface water were some of the highest ever recorded using standard collection methods. Higher abundances following storm events suggests that wet weather may mobilize microplastics from the surrounding watershed.

The dominant shape category was fibers, followed by fragments, with 87% of the fragments and 53% of fibers identified as plastic. The composition of many fibers could not be determined due to anthropogenic dyes masking the underlying material.

Sediment in the lower south Bay had more microplastics

Sediment samples were collected at 20 sites to assess baseline conditions, and evaluate spatial distribution including the influence of urban stormwater and wastewater discharges. Samples were collected from the San Francisco Bay and a less-urban reference site nearby, Tomales Bay, to evaluate urban influence.

The highest concentrations of microparticles in sediment were measured in the Lower South Bay, which is strongly influenced by



Measuring microplastic samples • Photo by Xia Zhu wastewater and urban stormwater discharges. Concentrations at the reference site, Tomales Bay, were among the lowest observed. Microparticle and microplastic concentrations in Bay sediment were higher than those reported in the majority of other regions investigated by other studies worldwide.

The dominant shape category in sediment samples was fibers, followed by fragments. Of the fibers analyzed with spectroscopy, 31% were confirmed plastic (most commonly polyester, cellulose acetate, and acrylic). Of the fragments, black particles that looked and felt like rubber dominated the samples (29% of fragments).

Jellyfish and plastic bag • Photo courtesy of Save the Bay

Prey fish consume fibers

Two species (anchovy and topsmelt) were collected from six sites in the Bay and two sites in the reference area (Tomales Bay) to evaluate the presence of microplastics in prey fish. Prey fish are important to assess because they represent a critical link between contaminant concentrations in sediment and sea water and the food web. They may also be an indicator of exposure to larger predators and humans.

Prey fish from the highly urbanized San Francisco Bay had higher particle counts than fish from the more rural reference area, Tomales Bay. Fibers were particularly common, and while most of the fibers were dyed and therefore manmade, few could be identified conclusively as plastic. Thirty eight percent of fish from the Bay had consumed microplastics, with an estimated average of between 0.2 and 0.9 non-fiber microplastics per fish and between 0.6 and 4.5 plastic fibers per fish. The microplastic counts and detection frequencies in the Bay were comparable to counts reported in many other locations.

High levels of rubbery fragments and other microplastics and microfibers found in stormwater

This study measured microparticles in urban stormwater from 12 small tributaries (small rivers and streams) comprising 11% of the watershed drainage area to San Francisco Bay (6% of total flow to Bay; the majority of flow is from the larger Sacramento and San Joaquin Rivers). The small tributaries varied in urban and non-urban land uses and were distributed across the region.

Microparticles were identified in urban stormwater from all 12 small tributaries, containing between 1.3 and 30 microparticles per liter. Fragments (59%) and fibers (39%) constituted nearly all microparticles sampled. Nearly half the sampled microparticles were black fragments with a rubbery texture, some of which were identified as rubber. The source of these rubbery particles are not known with certainty, but other studies indicate vehicle tire wear as a likely source (Boucher and Friot, 2017; Kole et al., 2017).

A total microplastic discharge of 7 trillion microparticles to the Bay per year from adjacent small tributaries was estimated using the previously developed Regional Watershed Spreadsheet Model (RWSM). This estimate is 300 times greater than the estimated combined annual load from all the wastewater treatment plants surrounding the San Francisco Bay.

Wastewater samples dominated by microfibers

Microparticles were captured from the effluent of eight Bay Area wastewater treatment plants that represent over 70% of the overall effluent flow to the Bay. The eight facilities were geographically distributed, varied in flow rates from 90 to 630 million liters per day (24 to 167 million gallons per day), and employed a variety of secondary and more advanced treatments.

Microparticles were identified in effluent from all eight facilities, discharging an average of 0.063 microparticles per liter. Fibers were the most frequently identified shape of microparticles. While 19% of the fibers were unmistakably plastic, another 50% were clearly manufactured due to the presence of dyes and coloring agents, but could not be definitively identified as plastic or non-plastic. Fragments were the second most abundant shape, and of those that underwent spectroscopy, 54% were identified as plastic, with most being polyethylene (31%).

Facilities employing more advanced treatment including dual media filtration had lower microparticle concentrations than other (secondary treatment) facilities, suggesting that this enhanced treatment may reduce microparticles as well as other pollutants.

Testing microplastic samples • Photo by Krystle Moody Wood

Approximately 91 million microparticles per day are discharged by the eight facilities. Assuming similar discharges among the remaining facilities, approximately 130 million microparticles are discharged per day to the Bay in treated wastewater effluent, or approximately 47 billion microparticles annually, of which 17 billion are estimated to be plastic.

Quality control samples reveal microfibers are everywhere

As part of the San Francisco Bay Microplastic study, we instituted rigorous field and laboratory sampling protocols including collection of quality control blank samples. A field blank is collected to see if samples have been contaminated during field sampling or transport, while a laboratory blank will help to identify any potential contamination of the samples during analysis.

Fibers were widely detected in the field and laboratory blanks. In some instances, the fibers in the blanks could be traced back to a specific source (e.g., orange life jackets used on the ship); however, in most instances, the source of the fibers could not be identified, attesting to the pervasive presence of fibers in the indoor and outdoor environment. These fibers may be transported through air deposition.

Related Bay Area microplastics research

A pilot study conducted in 2015 by the RMP documented levels of microparticles in Bay surface water greater than reported in the Great Lakes and Chesapeake Bay (Sutton et al., 2016). This study also found that microparticles, including microplastics, passed through Bay Area wastewater treatment plants and that fibers made up most of the microparticles in wastewater effluent.

During the wet season of 2016, SFEI evaluated the efficacy of rain gardens for removing microplastics in stormwater. Influent into the garden and effluent after percolation through the garden were sampled over the course of three individual storms and then analyzed for microplastics (Gilbreath et al, 2019). The small catchment (approximately one acre) analyzed was located along a major urban transit corridor. Levels of microplastics and other particles in stormwater samples collected before and after flowing through the rain garden indicated that it removed over 90% of the material. These results suggested that rain gardens may provide additional societal benefits beyond capturing and filtering legacy contaminants. Further research on larger and alternative green stormwater infrastructure landscapes is necessary to understand efficacy and optimal employment with respect to microplastics.

4 RECOMMENDATIONS FOR SAN FRANCISCO BAY

Source reduction is the most efficient and cost-effective option to prevent plastic pollution, compared to end-of-pipe solutions such as clean-ups and catchment systems. The following recommendations are informed by scientific evidence from the San Francisco Bay Microplastics Project (Sutton et al, 2019). These recommendations primarily focus on plastic use or source reduction, with some options for capture of microplastics before they enter wastewater or stormwater systems. Recommendations also emphasize innovation, design, and household interventions to reduce regional microplastic pollution.

Pelicans over the Bay at sunset • Photo by Shira Bezalel, SFEI

RECOMMENDATION #1:

Support policies that reduce single-use plastics and plastic packaging in the Bay Area and statewide

Project results

- *Foam, plastic fragments, and plastic films, with potential sources including single-use plastic items, were detected in San Francisco Bay surface water and stormwater samples, and to a lesser extent sediment samples.*
- *Most of the foam microparticles in the surface water samples were polystyrene (53%), between 0.5 and 2 mm in size, and white in color, consistent with foamed polystyrene used in single-use items, such as food containers and packaging materials.*
- *Most fragments in the surface water samples were between 0.5 and 2 mm in size and were white or clear hard plastics (47% polyethylene, 25% polypropylene) which could be from single-use plastic items breaking down on streets and shorelines around San Francisco Bay.*

The Bay Area has many ordinances that limit single-use plastic items, including plastic bags, plastic drinking straws, and expanded polystyrene (a.k.a. "Styrofoam") takeout containers. Single-use plastic item bans have been in place for the past ten years. More recently, on January 22, 2019, the Berkeley City Council approved the Disposable Foodware and Litter Reduction Ordinance, the most ambitious and comprehensive policy in the U.S. aimed at reducing single-use disposable foodware. Berkeley's comprehensive ordinance can act as a model ordinance that other communities can refer to. Model ordinances have proven useful in guiding municipal and regional plastic bag and expanded polystyrene bans.

While these efforts have resulted in new legislation and regulation, raised awareness, and have galvanized communities and coalitions into action, it is difficult to determine, without significant pre- and post-implementation monitoring, whether or not these victories have impacted the amount of plastic entering our watersheds.

Suggested actions

POLICY

(1) Comprehensive statewide legislation to reduce single-use plastics and plastic packaging in California;

(2) Additional cities in the Bay Area should explore comprehensive policies based on the ordinance passed in Berkeley; and

(3) Regional policy (spanning more than one municipality, countywide, or statewide) to eliminate multiple single-use plastic disposables.

COLLABORATION / INNOVATION

(1) Work with other entities that monitor and track expanded polystyrene upstream (Surfrider Foundation, Break Free From Plastic, Clean Water Action, etc.) to better understand the sources and pathways and define solutions;

(2) Support and explore innovation of alternative materials that could replace expanded polystyrene;

(3) Encourage Bay Area stakeholders to build educational campaigns to increase the popularity of reusable items and work with influencers, young activists, and schools; and

(4) Encourage collaboration between food service industry and public health community to make it easier and more accessible to use reusables.

SCIENCE

(1) Require monitoring alongside policy efforts to track efficacy and impacts of legislation (before and after implementation);

(2) Alternatives should be analyzed for potential health impacts; and

(3) Evaluate existing comprehensive policies and foodware ordinances to scale regionally.

RECOMMENDATION #2:

Explore green stormwater infrastructure management options to reduce microplastics from entering San Francisco Bay

Project results

- *Microparticle concentrations ranged from 1.3 to 30 microparticles per liter at the 12 small tributaries analyzed in the project.*
- *Stormwater measurements calibrated to Bay Area land uses models suggest that rivers, streams and stormwater systems contribute more than 7 trillion microplastics annually.*
- *A related SFEI study found that bioretention rain gardens may reduce microplastics from entering stormwater systems.*

Green stormwater infrastructure, also referred to as "low impact design," is a stormwater management approach used in urban areas that utilizes the natural hydrologic processes of the landscape by increasing source retention, detention, and filtration of stormwater runoff.[5] Examples include permeable pavement, rain gardens (bioretention systems), and tree-well planters.

As described above, the SFEI study of a Bay Area rain garden supports the use of bioretention as a management option for reducing flows and regulating contaminant discharges, as required by water quality permits (Gilbreath et al, 2019). Anthropogenic microparticles, including microplastics, were also well-captured by the bioretention rain garden (over 90% removal).

In the Bay Area, green stormwater infrastructure has been required by the Regional Water Quality Control Board as defined in municipal regional permits. Green stormwater infrastructure attenuate the flow of stormwater to the Bay by directing the stormwater runoff to small basins that are designed to facilitate percolation of the water through soil or a specially prepared matrix to remove contaminants such as mercury and PCBs. Municipalities are required to set goals for green stormwater infrastructure deployment and then track progress toward meeting the planned goals.

Stormwater programs are also responsible for reporting their progress via annual reports submitted to the Regional Water Quality Control Board. These reports are recorded on the Water Board's website.[6] In addition, GreenPlan-IT Tracker[7] is a

5 https://www.epa.gov/green-infrastructure/what-green-infrastructure

6 https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/stormwater/MRP/Annual_Reports1.html

7 http://gptracker.sfei.org

tool that helps to determine the effectiveness of the Bay Area's green stormwater infrastructure in intercepting contaminants before they enter the Bay.

Suggested actions

POLICY

(1) Where possible, support existing and encourage new green stormwater infrastructure in the Bay Area.

SCIENCE

(1) Assess locations for green stormwater infrastructure adjacent to the San Francisco Bay; and

(2) Assess microparticle and microplastic filtration effectiveness for other types of green stormwater infrastructure.

El Cerrito Rain Garden• Photo by SFEI

RECOMMENDATION #3:
Identify and prioritize intervention points for microfibers around filtration

Project results

- *Microparticles were identified in effluent (wastewater) from all eight facilities assessed by the project, discharging an average of 0.063 microparticles per liter.*
- *Fibers were the most frequently identified shape of microparticles in wastewater. While 19% of the fibers were unmistakably plastic, another 50% were clearly manufactured due to the presence of dyes and coloring agents, and may also be plastic.*

Several independent studies indicate textile washing releases large quantities of microfibers to wastewater systems, supporting discussion of potential interventions. Wash water can be filtered at various intervention points, and as we assess the most effective options, several key questions emerge.

How can microfibers be removed most effectively from effluent, and which technologies can be implemented and scaled quickly? Several new filtration technologies and manufacturing innovations that target consumer household and commercial facilities have been developed. Consumer facing devices include the Cora Ball, Guppy Friend, Filtrol, Lint LUV-R and others, which are all designed to capture microfibers in household laundry. Additionally, filtration socks, which attach to washing machine piping that drains into the sink, have historically been used to control particles from going down the drain. Recent studies have evaluated the efficacy of several of these devices in removing microfibers from effluent, finding a broad range of removal efficiency, from 26% (Cora Ball) to 87% (Lint LUV-R) (McIlwraith et al., 2019).

In considering legislative or regulatory approaches to filtration, questions of cost, accountability, and target audience have been raised:

- Cost: If targeting the residential sector, should consumers be asked to purchase devices? Are local tax rebates or incentive programs available to shift the cost burden from individuals to manufacturers? Will there be educational programs offered to ensure proper installation and maintenance to ensure products are effective?
- Target audience: Should policy approaches target household washers, commercial laundromats, institutional laundry facilities, or all three? What additional information or data might be useful to prioritize?

- Accountability: Does introducing mandatory filtration remove responsibility from the manufacturing sector to address the problem from a design standpoint?

Wastewater treatment plants already serve as an intervention point, and independent studies have demonstrated that common treatment technologies remove a large portion of microplastics and microfibers from treated effluent. Project results suggest that facilities, employing tertiary treatment that includes advanced filtration discharge, lower overall concentrations of microparticles than facilities using secondary treatment only. While this study was not designed to assess the removal efficiency of different wastewater treatment technologies, this topic may merit further exploration.

Nevertheless, it is important to note that additional end-of-pipe wastewater treatment is challenging for individual facilities. In addition, the particles that are captured via large-scale wastewater treatment do not disappear, which is also true for any filtration system attached to a washing machine. Treatment facility waste products like biosolids, which include captured microplastics, can be applied as fertilizer to agricultural lands. This results in a redistribution of microplastics in the environment and potential introduction into the local watershed. Fibers that are removed from filtration devices should be placed in the garbage and disposed of in a local landfill.

Suggested actions

POLICY

(1) Support a pilot study or ordinance to mandate filtration on institutional, commercial and/or residential washing machines, with monitoring built in to determine effectiveness. If effective, pursue state legislation around most effective option; and

(2) Explore rebates for installation of filtration systems on commercial laundromats, institutional laundry facilities, and residential washing machines.

COLLABORATION / INNOVATION

(1) Work with the Association of Home Appliance Manufacturers and stakeholders to understand the feasibility and limitations of filtration systems that are built into the washing machine; and

(2) Work with new stakeholder groups (representatives and experts from carpet, washing machine, dryer, filtration, air quality, etc.) to identify other potential sources of microfibers.

SCIENCE

(1) Pilot filtration study comparing commercial laundromats, institutional laundry facilities, and residential washing machines.

RECOMMENDATION #4:
Support the development of a San Francisco Bay Microplastics Management Strategy to reduce microplastics

Project results

- *Within the timeframe of the project, regulators and stakeholders within the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) determined that microplastics, listed as an emerging contaminant, should be reclassified from "possible concern" to "moderate concern." Currently there is no management strategy in place to reduce microplastics in the Bay.*

The RMP provides water quality regulators with the information they need to manage and protect Bay water quality. The RMP has monitored the Bay for contaminants of emerging concern for over a decade, and performed the pilot study of microplastics in the Bay. As with the present study, levels observed in this previous study were higher than other water bodies near urbanized regions of the U.S. (Eriksen et al., 2013; Yonkos et al., 2014).

The RMP developed a monitoring and science strategy for microplastics in San Francisco Bay; however, a regional strategy for the management of this class of contaminants does not yet exist. The RMP originally classified microplastics as a "Possible Concern" for the Bay within its Tiered Risk Framework for unregulated, emerging contaminants, as the lack of ecotoxicity thresholds meant there was uncertainty as to whether current Bay levels were a risk for wildlife. Considering the EU's recent proposal to classify microplastics as a "non-threshold contaminant," their persistence in the environment, their potential for bioaccumulation (gradual accumulation of chemicals in an organism), the difficulty associated with their removal, as well as the projected increase in the global manufacture of plastics, and increased public awareness and concern, the RMP has reclassified microplastics as of "Moderate Concern" for the Bay.

The increasing level of concern about microplastics in San Francisco Bay suggests the need to actively manage this contaminant. Currently, no single agency is mandated to monitor or regulate microplastics in wastewater, stormwater, or in the Bay itself. In contrast, a recent statewide bill (SB1422) requires that the State Water Resources Control Board develop and carry out standardized monitoring for microplastics in drinking water, while defining safe levels of microplastics for the public.

Other regional agencies that play a role in regulation of plastic pollution include:

- San Francisco Bay Conservation and Development Commission (BCDC) and the California Coastal Commission.
- The San Francisco Bay Regional Water Quality Control Board, which regulates trash through municipal and industrial stormwater permits, mandated by the State Water Resources Control Board.
- The Ocean Protection Council (OPC), which was recently mandated through SB 1263 to develop a Statewide Microplastics Strategy in collaboration with the State Water Resources Control Board, the Office of Environmental Health Hazard Assessment, and other entities. This strategy is expected to provide regulatory agencies with the background information and evidence to move forward with solutions.

A strategic next step would be to incorporate the scientific results and recommendations determined by this project into the Statewide Microplastics Strategy that OPC is spearheading.

Suggested actions

POLICY

(1) Results and recommendations from San Francisco Bay Microplastics Project should be incorporated into the OPC Statewide Microplastics Strategy; and

(2) A Microplastics Management Strategy that lays out priorities and actions to reduce microplastics in San Francisco Bay should be developed.

COLLABORATION / INNOVATION

(1) Explore capacity of regional regulatory agencies best positioned to develop, manage, and implement Microplastics Management Strategy.

RECOMMENDATION #5:
Encourage textile industry to standardize methods to understand microfiber shedding

Project results

- *Microfibers were widely detected in all samples and were the dominant shape category in surface water, wastewater, fish, and sediment samples.*
- *Microfibers were detected in field and laboratory quality control samples, suggesting deposition from the air.*
- *Spectroscopy was carried out to determine the percentage of microfibers that were plastic, with up to 53% of the fibers in the surface water samples being plastic. 24% of microfibers in surface water samples were found to be polyester.*

A significant collaborative effort is underway to understand how to monitor and quantify microfibers, including plastic microfibers, shed by synthetic textiles. The textile industry, including apparel and textile fabric manufacturers (including carpeting, towels, and upholstery) is highly involved and understands the need to quantify fiber loss through the lifecycle of textiles (during production of textiles, garments, or other articles; wear or use; washing and drying; recycling or disposal). Several entities related to textiles have initiated discussions on fiber loss or microfiber shedding. This has primarily been led by the apparel industry, though the washing machine and carpet industry are entering the discussions.

As noted previously, the textile industry employs technical definitions of the term microfiber that differ from those used by scientists studying microplastics; greater clarity and alignment of terminology is likely to be an important step in coordinating efforts from different fields.

The Outdoor Industry Association (OIA) and the European Outdoor Group (EOG), the main trade organizations for the outdoor industry, recognize the industry's potential contribution to microfiber pollution. The OIA has a Sustainability Working Group subgroup focused on microfibers that has created a resource library to map the landscape of organizations, researchers, and institutions exploring both impacts and possible solutions. OIA and EOG were part of the development of the "Microfiber Action Roadmap."[8]

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8 https://oceanconservancy.org/wp-content/uploads/2018/01/Microfiber-Action-Roadmap.pdf

Below are additional organizations working on standardizing methods to measure microfiber shed rates:

- The American Association of Textile Chemists and Colorists (AATCC) provides test method development, quality control materials, educational development, and networking for textile and apparel professionals throughout the world. AATCC has a series of committees, including AATCC Committee RA 100, Global Sustainability Technology, that is developing a new test method for fiber release during laundering.
- ASTM International is an international standards organization across more than 140 countries, which develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. A revision to an existing standard is under development by their committee that focuses on fiber release of fabrics.[9]

Suggested actions

POLICY SUPPORT

(1) Legislation that supports standardization of these methods in California is encouraged to bring attention to microfibers.

COLLABORATION / INNOVATION

(1) Better communication among existing efforts, regionally and globally;

(2) Work with stakeholders to standardize definitions of microfibers; and

(3) Increase communication and information sharing among AATCC, OIA, EOG, ASTM, local entities, and others focusing on solutions to microplastics in San Francisco Bay.

SCIENCE

(1) Help support the development of sheddability standards and methods in partnership with input from stakeholders, including AATCC, OIA, EOG, ASTM, scientists, and the environmental community. The standards will push innovation on the textile industry; and

(2) Identify possible microfiber sources and build a conceptual model that can explain possible microfiber pathways and sources.

9 https://www.astm.org/DATABASE.CART/WORKITEMS/WK62604.htm

RECOMMENDATION #6:
Better identify microplastic sources and pathways in stormwater systems

Project results

- *Stormwater measurements calibrated to Bay Area land uses models suggest that rivers, streams and stormwater systems contribute more than 7 trillion microplastics annually.*
- *This suggests that stormwater input of microparticles is 300 times greater than the estimated combined annual discharge from all the wastewater treatment plants surrounding the San Francisco Bay.*
- *Fragments (59%) and fibers (39%) constituted nearly all microparticles identified in stormwater samples. Nearly half of all microparticles in stormwater samples were identified as black rubber fragments, potentially originating from tire wear.*

The potential sources of the microparticles and microplastics found in stormwater are complex, and particle movement within the watershed is likely influenced by myriad factors including land use, quantity of impervious surfaces, and proximity to roadways. Additionally, industrial land use areas may be contributing higher levels of microparticles to stormwater systems. Industrial activities are often subject to discharge permit requirements; however, many industries do not face microplastics discharge regulations.

Very few studies of microplastics have been conducted on stormwater, despite its potential to be a major pathway for environmental contamination. The understanding of outdoor urban sources of microplastics to stormwater is limited. In particular, larger amounts of microparticle pollution related to industrial land use has not been noted previously, and it is possible that this correlation is in fact driven by other factors.

Greater insights regarding the sources of these microplastics, as well as how they enter the stormwater system, is needed in order to adequately identify strategic and cost-effective solutions. A conceptual model that can identify relevant factors and predict which types of watersheds are likely to discharge higher levels of microplastics will inform a region-specific, targeted approach to reducing microplastic pollution.

Additionally, rubbery particles were identified in stormwater samples as well as sediment samples. These rubbery particles may be associated with vehicle tires or other sources. As tires wear and rub on road surfaces, tire wear particles have the potential to enter the environment through a variety of pathways (e.g., stormwater, air deposition, etc.). Rubber tire particles have been documented in aquatic environments in a few previous studies. Additional sources of rubber fragments to the environment may include artificial athletic fields and playgrounds, among others. The sources and quantities of rubber fragments and the impacts on wildlife health should be further explored.

Suggested actions

POLICY ACTIONS

(1) Support the Regional Water Quality Control Board's effort to regulate, mitigate, and monitor microplastics through their discharge permits, including industrial discharge permits.

COLLABORATION / INNOVATION

(1) Install more green stormwater infrastructure to capture microplastics.

SCIENCE

(1) Support research to develop a conceptual model of microplastics in stormwater, which would explore sources of microplastics and transport within the watershed, and identify the importance and influence of land use and other landscape attributes on the concentration of microplastics in stormwater runoff; and

(2) Understand sources, quantities, and impacts of rubber fragments in San Francisco Bay.


Stormwater culvert in Berkeley • Photo by Shira Bezalel, SFEI

RECOMMENDATION #7:

Increase collaboration on plastic pollution reduction efforts

Project results

- *During the project's Policy Committee meetings, organized to discuss results and solutions, it became clear that better communication between stakeholders, sharing of information, and collaboration on plastic pollution-related projects and efforts would be beneficial.*

Many cities around the nation are working to reduce their plastic waste footprint and setting waste reduction goals. California's Trash Policy (Trash Amendments), an enforceable state goal of zero trash present in any ocean waters, bays, or rivers by 2030, has motivated Californian cities to begin documenting the presence of plastic waste, identifying sites of high concern, and implementing management actions. The current lack of communication in some cities may be due to the fact that microplastics are generally unregulated, and too small to be included within the standard definition of "trash".

However we do see collaboration on different levels. Locally, the Trash Data Dive,[10] a stakeholder meeting that occurred in Fall 2018, brought together stakeholders and scientists working on trash. Nationally, a number of statewide and international ocean conservation organizations collaborated on the recent Better Alternatives Now 2.0 Report (2017 Plastic B.A.N. List) to identify trends in plastic lost to the environment in order to focus policy and innovation efforts on the top contributors (Allen et al., 2017).

As a global movement, Break Free From Plastic Movement,[11] a coalition of more than 1,500 groups is collaboratively demanding massive reductions in single-use plastics and pushing for lasting solutions to the plastic pollution crisis. In all cases, micro- and macroplastics are targeted.

A regional coalition that brings together urban and ocean trash and microplastic efforts would be beneficial to share information that can support each other's work. More

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10 https://www.sfei.org/projects/california-trash-monitoring-methods-project#sthash.nvm6LkNj.dpbs

11 https://www.breakfreefromplastic.org/

groups should be added to the conversation to better connect actions occurring in urban areas to the ocean. The Bay Area would be a key area to create these cross-sector collaborations.

Suggested actions

POLICY

(1) Mandate standardized, open source data collection on trash, macroplastics, and microplastics; and

(2) Establish a data portal where all plastic pollution and trash data is stored and openly accessible to interested stakeholders.

COLLABORATION / INNOVATION

(1) Set up a regional coalition that brings together urban trash-focused work and ocean macro- and microplastics efforts to share data that can support each other's work;

(2) Support additional solution oriented meetings that bring together a range of stakeholders;

(3) Identify an agency or entity to manage a platform for sharing trash and microplastics monitoring protocols; and

(4) Share project results and outcomes with participants at the Trash Data Dive that occured in Fall 2018 in the Bay Area.

SCIENCE

(1) Summarize the macroplastics/trash trends upstream in the Bay Area with available data;

(2) Combine microplastics data with macroplastics/shoreline clean-up data in Bay Area; and

(3) Develop standardized monitoring methods and terminology/data reporting to allow for apples-to-apples comparisons.

RECOMMENDATION #8:
Support innovation to address microplastic pollution in San Francisco Bay

Project results

- *During the project's Policy Committee meetings, innovations were identified as important solutions.*

It is clear that plastic pollution will not be solved without innovation, especially with plastic production projected to increase exponentially. Innovation can range from designing refillable and reusable systems, creating new alternative materials, and designing better products to developing new technologies to monitor microplastics in the environment. As the plastic pollution movement has grown, foundations, nonprofits, and companies have released innovation challenges geared towards funding new ideas to tackle the issue of plastic pollution.

One of the first challenges that focused on plastic pollution was the Think Beyond Plastic Challenge, now called the Think Beyond Plastic Innovation Center. The international program brings together innovators, entrepreneurs, industry, scientists, engineers, and consumer advocates and pushes individuals and companies to rethink the way plastic products are being made, used, and reused. Similar challenges are being developed from entities around the world. Most recently, National Geographic announced their Ocean Plastic Innovation Challenge.

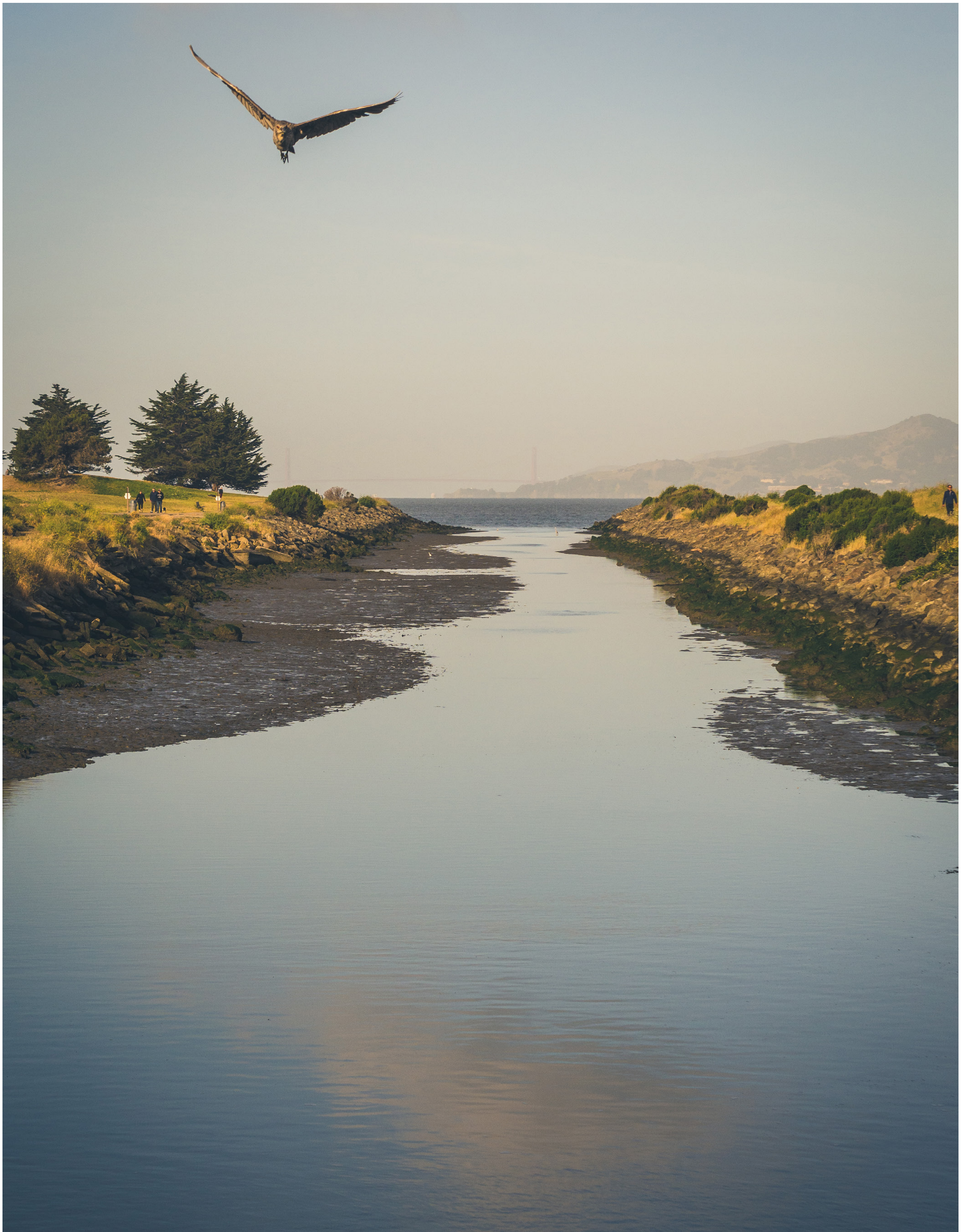
A similar trend is seen in the Bay Area. Schmidt Marine Technology Partners and the Ocean Solutions Accelerator are two examples of Bay Area entities established to better connect technological innovation with ocean conservation efforts. Schmidt Marine Technology Partners supports the development of ocean technologies with compelling conservation and research applications. The Ocean Solutions Accelerator, part of Sustainable Ocean Alliance, partners with technology companies to provide guidance and resources needed to scale their businesses.

The Bay Area is already a center for innovation, and with the high number of philanthropists and an environmentally conscious public, there may be interest from local companies, foundations, and individuals to fund and support a San Francisco Bay focused innovation challenge.

Suggested actions

COLLABORATION / INNOVATION

(1) Explore feasibility and possible funders to establish a Bay Area-focused innovation challenge to find solutions to plastic and microplastics pollution in the region.



Point Isabel Regional Shoreline • Photo by Shira Bezalel, SFEI

RECOMMENDATION #9

Support microplastic research to monitor impacts in the region over time

Project results

- *The project identified four critical research needs: a) long-term monitoring to establish trends and to measure the effects of management actions; b) baseline microplastic monitoring in air; c) better understanding the ecological and ecotoxicological impacts of microplastic pollution; and d) understanding of how to phase out harmful chemicals added to plastic products.*

The San Francisco Bay Microplastics Project collected baseline data on microplastics throughout San Francisco Bay, with the goal of increasing our understanding of the sources and pathways of microplastic pollution in the region. Long-term monitoring is needed to track trends and evaluate whether microplastics reduction policies are having a positive impact. For example, the Federal Microbead-Free Waters Act, passed in 2015, phased out the sale of products with microbeads by July 1, 2018. The field work conducted during this project, completed prior to this deadline, indicates microbeads are still being discharged to the sewer system. Levels of microbeads observed in wastewater samples collected in years after the ban should therefore be compared to current levels to assess the real world impacts of this policy.

Additionally, field blanks collected during the project suggest that airborne microplastics could be a potential pathway for microplastic contamination in San Francisco Bay. Our field blanks had microfiber contamination, with the highest amount of contamination found in blanks collected alongside the surface water samples. There are few studies of microplastics in air, but growing interest within the scientific community to better understand this pathway.

Results of the fish samples suggest that microparticles are routinely ingested by prey fish, with 99% of the fish sampled having microparticles in their gut (a majority of the particles being fibers). Monitoring additional fish in the region, including sport fish consumed by humans, may be helpful to better understand if there are pathways for chemicals from the plastic pollution to transfer during consumption and impact human health. Additionally, tissue sampling may be appropriate to understand if chemicals are transferred to the body of the fish from any plastic pollution inside the fish. Studies have identified that microplastics can negatively impact wildlife in a variety of ways, including physical impacts, but there is uncertainty about adverse effects of these chemicals to aquatic wildlife.

Moreover, recent attention has been given to the effects of microplastics on human health based on our interaction with plastic food packaging. This June marked the first Unwrapped Conference,[12] which focused on the health risks of plastics and food packaging chemicals. Currently, in the US, consumers don't have easy access to information about the chemicals used in products and packaging. More information can be found in the Food Packaging Forum.[13] This raises another opportunity for research to determine which chemicals can be phased out of products that are coming in contact with our food.

Suggested actions

POLICY

(1) Funding for periodic microplastics monitoring in the San Francisco Bay Area to evaluate the effectiveness of Federal Microbead-Free Waters Act and other current and future policies; and

(2) Funding for additional research to evaluate concentrations of airborne microplastics, and ecological (marine and terrestrial) and human health impacts of microplastics.

COLLABORATION / INNOVATION

(1) Work with local universities to prioritize research on microplastics in San Francisco Bay; and

(2) Work with the textile industry to understand existing best practices to limit airborne contamination and ways to reduce shedding.

SCIENCE

(1) Long-term monitoring of microplastics in the San Francisco Bay Area;

(2) Study to identify pathways and sources of airborne microplastics;

(3) Study to quantify microplastics in fish consumed by humans, along with tissue studies to understand any chemical transfer; and

(4) Study to determine the potential impacts of microplastics and plastic-related chemicals to ecological and human health.

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12 https://www.unwrappedconference.org/

13 https://www.foodpackagingforum.org/

RECOMMENDATION #10:
Educate consumers, including the youth, on ways individuals can reduce microfibers from entering San Francisco Bay

Project results

- *While the stakeholders and partners involved in this project agree that source reduction, policy change, and design innovation are higher priorities in addressing microfiber contamination, there is still a role for public education on best management practices to reduce the amount of microfibers that enter the wastewater system. Simple, low cost techniques for proper washing of textiles can at least slow the rate of microplastic contamination while longer term solutions are developed. Additionally, project results and educational materials generated by the project should be shared with partners to distribute results to students, teachers, and the public.*

Multiple outdoor industry brands are working with the Vancouver Aquarium's Ocean Wise Plastics Lab to understand microfibers in household laundry effluent, wastewater treatment plants and the ocean, with a goal to identify sources and fate of microfibers.[14] The study aims to look to smarter textile design, laundry best practices, and wastewater engineering changes that could stem the release of microfibers. The project has identified best practices to reduce microfiber release during laundry, including:

- Less frequent washing;
- Use a front loading washing machine; and
- Install a filtration device or lint trap on washing machines.

The current trends and results related to plastic microfiber research should be included in new environmental curricula and educational materials that reference this project, where possible. 5 Gyres plans to incorporate results from this project in the Catch the Waves educational curriculum that was designed to scientifically engage middle and high school students in their communities through the lens of plastic pollution.[15]

14 https://www.aquablog.ca/2019/02/27886/

15 https://catchthewave.blue/

Suggested actions

COLLABORATION / INNOVATION

(1) Distribute educational materials generated by this project to partners, local NGOs, and teachers as an educational resource;

(2) Incorporate project results into future environmental curriculum, including 5 Gyres' Catch the Wave Curriculum; and

(3) Collaborate and share results beyond Bay Area, including researchers at Vancouver Aquarium.

Coyote Creek cleanup • Photo courtesy of Save the Bay

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APPENDIX A

Policy Advisory Committee

Table A-1. Policy Advisory Committee for the San Francisco Bay Microplastics Project.

	Name	Affiliation
1	Miriam Gordon	Upstream
2	Chelsea Rochman	University of Toronto
3	Christopher Lester	San Francisco Department of the Environment
4	Sean Bothwell / Natalie Caulk	California CoastKeeper
5	Krystle Wood	Textile Consultant / Materevolve
6	Nick Lapis / Robert Nunez	Californians Against Waste
7	Elissa Foster	Patagonia
8	Karin North	City of Palo Alto, Treatment Plant
9	Trent Hodges / Shannon Waters	Surfrider Foundation
10	Genevieve Abedon	Eco Consult / Clean Seas
11	Leslie Tamminen	Clean Seas / 7th Generation Advisors
12	Chris Sommers	EOA, Inc.
13	Holly Wyer	Ocean Protection Council
14	Sherry Lippiatt	NOAA (National Oceanic and Atmospheric Administration)
15	Jacqueline Zipkin	EBDA (East Bay Dischargers Authority)
16	Nirmela Arsem	EBMUD (East Bay Municipal Utility District)
17	Allison Chan	Save the Bay
18	Kevin Messner	Association of Home Appliance Manufacturers (AHAM)
19	Tony Hale	SFEI
20	Michael Shen	Schmidt Marine Tech
21	Alexander Black	Microfiber Solution
22	Carolynn Box	5 Gyres
23	Anna Cummins	5 Gyres
24	Haley Haggerstone	5 Gyres
25	Ella McDougall	5 Gyres
26	Meg Sedlak	SFEI
27	Becky Sutton	SFEI
28	Diana Lin	SFEI
29	Cambria Bartlett / Emily Bartlett	Heirs to Our Oceans

APPENDIX B

Existing policies and innovation in the Bay Area and beyond

Solutions to plastic pollution include education and behavior change, policy action, design change, and innovation. Note that these solutions are viable for both macro- and microplastics. A summary of policy action types is presented in Table B-1.

Table B-1. Plastic pollution policy action types and examples.

Policies to Prevent and Reduce Plastic Pollution	
Preventative / Reduction Policies	***Examples***
Single-use Bans	Food Service Waste Reduction Ordinance in San Francisco (bans expanded polystyrene disposable food ware); Statewide Plastic Bag Ban in California; National Microbead Ban
Multi / Comprehensive Bans	Berkeley Single-Use Foodware and Litter Reduction Ordinance (bans several single-use items)
Design / Extended Consumer Responsibility	Recycled content requirements, Leash the Lid
Source Reduction Goals	City zero waste goals
Post Manufacturing Policies	Examples
Filtration	LUV-R, Filtrol, Cora Ball, Guppy Bag, others
Structural Requirements	California Trash Policy, Trash Catchment Basins
Point of Purchase	Hang Tag, Certifications (Ex. Surfrider's Ocean Friendly Restaurant), Customer discounts for using reusable items
Economic Disincentives	Fees to manufacturer of problem products, Tax on cigarettes and single-use plastics
Others Suggested Policies	Examples
Promotion of Innovation	Funding to encourage innovation, including filtration systems, trash catchment tools, new textiles (Fiber weave / types)
Mandates Monitoring and Research	CA Litter Strategy, CA Microplastics Strategy, CA Ocean Plan

Local to global: A short summary of policies

California is leading the nation in statewide plastic pollution reduction efforts. Statewide policy leadership began as early as the mid-1980s, with several Californian cities passing expanded polystyrene ordinances (e.g., Berkeley and Manhattan Beach in 1988) to the more recent statewide plastic bag ban in 2016, the first in the country. Advocates in California introduced a motion in February 2019 that would require significant reductions (75%) in single-use plastic packaging by 2030 (AB1080[16]). Table B-2 presents statewide policies that are related to the plastic pollution reduction in California.

Table B-2. Statewide plastic pollution reduction efforts in California.

Statewide Plastic Pollution Reduction Efforts in California			
ACTION	***YEAR***	***DETAILS***	***ENFORCEMENT AGENCY***
Phase Out Single-Use Plastics	Proposed 2019	SB 54 would phase out the sale and distribution of single-use plastics by 2030 by setting up a state framework to address the issue.	N/A
Cigarette Ban at State Parks and Beaches	Proposed 2019	SB 8 will ban smoking cigarettes, cigars and other tobacco products at state parks and beaches.	Department of Parks and Recreation
California Ocean Litter Strategy	2018	SB 1263 requires development of a comprehensive statewide plan to reduce plastic pollution, including microplastics	OPC / NOAA
California Microplastics Strategy	2018	OPC is required to develop a Statewide microplastics strategy.	OPC
Plastic Straws On Request	2018	AB 1884 requires restaurants to offer straws only upon request.	State Department of Public Health
Food Service Packaging at State Agencies	2018	SB 1335 prohibits non-recyclable and non-compostable foodservice packaging at state facilities, including parks, beaches, colleges and fairgrounds.	Department of Resources Recycling and Recovery
California Ocean Plan: Trash Amendments	2015	Requires cities and counties to have zero trash (5 mm and above) entering water bodies by 2030	California State Water Board

16 http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201920200AB1080

Statewide Plastic Pollution Reduction Efforts in California			
ACTION	***YEAR***	***DETAILS***	***ENFORCEMENT AGENCY***
California Plastic Bag Ban	2016	Statewide plastic bag ban (SB 270) that prohibits most grocery stores, retail stores with a pharmacy, convenience stores, food marts, and liquor stores from providing single-use plastic carryout bags.	CalRecycle
California Plastic Microbead Ban	2015	Statewide plastic microbead ban (AB 888) which prohibits the sale of personal care products, such as soap, shampoo and toothpaste, that contain plastic microbeads. Two months later, the Microbead-Free Waters Act passed that made this ban span nationally.	N/A
Strategy to Reduce and Prevent Ocean Litter	2008	Strategy, developed in response to the 2007 OPC "Reducing and Preventing Marine Debris" Resolution, that called for a number of steps to reduce plastic pollution in the environment. This Strategy supported many of the statewide actions that are now in place.	OPC
California Bottle Bill	1986	Statewide incentive-based program that requires consumers pay a deposit on bottles of all materials, including plastic beverage bottles	CalRecycle
RELATED LEGISLATION	***YEAR PROPOSED***	***DETAILS***	***ENFORCEMENT AGENCY***
Microfiber Labeling	2018	AB 2379 would have required labeling on synthetic textiles that highlighted the potential environmental impacts of microfibers. This is the first statewide bill that focused on plastic microfibers.	N/A

State-wide policies

The State Water Board adopted the "Trash Amendments" to the Water Quality Control Plan .for Oceans Waters of California (Ocean Plan) and Part 1 Trash Provision of the Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries (ISWEBE Plan) in 2015. The amendments describes an enforceable state goal of zero trash, defined as 5 mm and above, present in any ocean waters, bays, or rivers by 2030. Cities and counties can meet these requirements by installing full capture systems on storm drains or by developing a trash reduction program that may include additional street sweeping, educational materials and programs, and local source control ordinances (e.g., single-use plastic item and comprehensive bans). Though the Trash Amendments do not focus on microplastics, they are often generated by larger single-use plastic items breaking up into smaller pieces. In the recent triennial reviews of the Ocean Plan, State Water Board staff identified microplastics and microfibers as a high priority issue that should be further investigated and managed.

The California Ocean Protection Council (OPC) and the California State Regional Water Quality Control are working with the Southern California Coastal Water Research Project (SCCWRP) and SFEI to test multiple trash monitoring methods with a goal of developing a library of methods with known levels of precision, accuracy, and cross-comparability of results, and linking these methods to specific management questions.[17] These tools will be valuable for reducing plastic pollution in the environment, no matter the size.

The definition of trash by the California State Water Resources Control Board does not include microplastics. The recent 2018 California Litter Strategy however, finalized by OPC and National Oceanic and Atmospheric Administration (NOAA) Marine Debris Program, is a comprehensive statewide plan that addresses plastic pollution from source to sea, including goals that address microplastics. Microplastics and microfibers are identified as priority items to address.

California legislature recently passed SB 1263, which requires the OPC to work with scientific experts to develop a California Microplastics Strategy, another step that makes California a leader in plastic pollution reduction efforts. The provisions of the bill complement the 2018 California Litter Strategy. The statewide strategy will build upon earlier policy decisions that created the California State Water Resources Control Board's Pre-Production Plastic Debris Program designed in 2007 to address microplastic pollution found along San Francisco Bay shorelines and wetlands. This program added special requirements to the industrial and municipal stormwater permits that requires best management practices when handling pre-production pellets and powders. As part of these requirements, each facility must submit a site-specific stormwater pollution reduction plan for approval. Based on a query of a state

17 https://sites.google.com/sfei.org/trash/

database of industrial dischargers, the Water Board identified 31 industrial sites in the Bay Area that are manufacturing plastic products. These sites are randomly inspected by Water Board officials, who have the authority to issue cleanup and abatement orders, if needed.

The California Microbead Ban passed in 2015 after microplastics were identified in San Francisco Bay (Sutton et al., 2016) and the Great Lakes (Eriksen et al., 2013). The statewide ban targeted personal care products containing microbeads, which are washed down the drain to wastewater treatment systems and then are discharged to the Bay and Pacific Ocean. The legislation required companies to phase out the use of microbeads in products sold in California. Ultimately, this law led to the national Microbead-Free Waters Act of 2015 that banned the use of microbeads in certain personal care applications.

Local: City and county

In addition to the local ordinances on polystyrene and plastic bags referred to earlier, California has been exploring comprehensive policies banning single-use plastics at the city and state level. Berkeley's Disposable Free Dining and Litter Reduction Ordinance,[18] passed in 2019, immediately requires utensils, straws, lids, and sleeves to be provided by request only; and by 2020, all takeout food containers must be compostable, vendors must charge an additional $.025 fee for disposables, and eat-in dining facilities must use reusable foodware. Other cities, including San Francisco, are considering similar ordinances.

The City of Santa Cruz continues to lead by passing a local ordinance that prohibits the tourist industry from providing single-use, "travel size" shampoos to customers, instead requiring that hotel owners provide refillable soap and shampoo containers. Santa Cruz is also discussing a comprehensive ban that would eliminate the sale of additional single-use plastic items, along with exploring options of installing filtration systems on washing machines at commercial laundry facilities.

As described above, many of the communities in the Bay Area are passing local ordinances to ban single-use plastic items. Close to half of expanded polystyrene bans are located in the Bay Area, many communities with watersheds that drain directly to San Francisco Bay.

The cities of Alameda and Oakland have mandated a 'straws on request' policy, while San Francisco prohibits the distribution of a more inclusive list of plastic items such as beverage lid plugs, cocktail sticks, toothpicks, and beverage stirrers. Such items are to be self-service or on request, and take-out containers and food-ware must be certified recyclable. This ban in San Francisco is part of the inclusive ban on polystyrene take-out containers, and requires the materials to be recyclable or compostable.

18 http://src.bna.com/FHH

Regional

The Ocean Conservancy and UC Santa Barbara's Bren School of Environmental Science and Management organized a Microfiber Leadership Summit in the fall of 2017. More than 50 representatives from companies, universities, nonprofits, and government agencies participated in a day long workshop to understand the state of the science and available solutions for microfiber pollution. The group agreed on five actions to work towards solutions on a national level, including:

- Developing a shared strategy to understand the challenges of plastic microfibers in the environment based on robust, peer-reviewed science. This resulted in a "Microfiber Roadmap" that calls out a timeline for creating such a strategy;
- Establishing consistent testing methodologies for measuring plastic microfiber shed rates from textiles and other materials;
- Better understanding of loss of microfibers through the life cycle of various products and materials. This included quantifying the sources and leakages of microfibers from the production, distribution, use, and end-of-life of microfiber-generating materials;
- Assessing the risks of plastic microfiber pollution to humans and ecosystems using a risk assessment (RA) framework; and
- Identifying existing industry best practices that can be rapidly implemented to minimize plastic microfiber loss. The Microfiber Roadmap has an end goal of 2022 to carry out the life cycle assessment and generate science-based solutions.

Global actions

The United Nations Environment Programme (UNEP) recently published a report called "Single-use Plastics: A Roadmap for Sustainability" that evaluates case studies from over 60 countries to provide an overview of plastic pollution, while also offering recommendations, mainly looking at actions governments can take towards solutions.[19] UNEP also has an interactive map that highlights policy efforts around the world.[20] The recommendations are broad, but encourage communities to target the most problematic plastics, consider best actions according to socio-economic standing, evaluate impacts, engage stakeholders, raise public awareness, promote alternatives, provide financial incentives, and include monitoring with initiatives.

The European Union also recently passed comprehensive legislation that will require 28 countries to reduce plastic pollution. The initiative bans single-use plastic products, including plastic straws and stirrers, single-use cutlery, some polystyrene items, and

19 https://wedocs.unep.org/bitstream/handle/20.500.11822/25496/singleUsePlastic_sustainability.pdf?sequence=1&isAllowed=y

20 https://www.unenvironment.org/interactive/beat-plastic-pollution/

plastic cotton buds by 2021 and also requires reducing plastics with no alternatives, mostly food packaging, by 25% by 2025. There is also a requirement for beverage bottles to be recycled at a rate of 90% by 2025. Additionally, cigarette butt litter will have to be reduced by 50% by 2025, and 80% by 2030.

In 2013, the European Union funded MERMAIDS, a program of the Plastic Soup Foundation, an environmental group located in Amsterdam, that focused on better understanding the loss of synthetic clothing fibers through laundering.[21] Along with multiple partners, Plastic Soup Foundation evaluated filtration systems on washing machines as a solution to microfiber pollution, as well as assessed detergent compositions that may reduce fiber release. The project found that a single load of laundry can release close to 20 million fibers, while also providing a set of methods to evaluate fiber release (Falco et al., 2018). Additionally, the project suggests that using liquid detergent and fabric softeners can help reduce fiber release (possibly by up to 35%).

Building upon this work, these four entities developed a white paper by multiple organizations that called out immediate microfiber solutions, including:

1. Educate individuals on the best practices for reducing fiber release during washing cycles (e.g., use low temperatures and fabric softener);
2. Use existing solutions, including technological filtration systems on the market;
3. Design textiles that shed less; and
4. Explore fabric design innovation.

From a textile design perspective, the MERMAIDS Project determined strategies to develop stronger fibers that result in less fiber release during washing. Fiber length, yarn twist and fabric density play a role in the number of fibers released by textiles during washing.

The Plastic Soup Foundation started an environmental campaign called the Ocean Clean Wash to identify steps to address microfiber pollution. Ocean Clean Wash gathered a broad range of stakeholders to work together to reduce synthetic microfiber release by 80% in the coming years by better understanding the entire product lifecycle and promoting solutions. The group formed a steering committee that includes multiple international NGOs and aims at increasing solutions through working with the fashion industry. Plastic Soup Foundation has hosted workshops, panel discussions, and meetings with the fashion industry. Most interesting was a meeting with 20 stakeholders in the fashion industry that explored all steps of the value chain, while discussion solutions and opportunities to solve microfiber pollution.[22]

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21 http://life-mermaids.eu/en/

22 http://oceancleanwash.org/solutions/

Innovation

Several technology inventions and initiatives to address plastic pollution have been designed over the last few years. Table B-3 describes systems that may be applicable in San Francisco Bay to reduce microplastics.

There have been several studies to test the effectiveness of filtration systems attached to washing machines to filter microfibers and microplastics from municipal wastewater. Washing machine filtration systems, such as LUV-R and Filtrol, show promise at filtering small particles from textiles. Concerns have been raised about consumers cleaning the filter appropriately to ensure filters work effectively and proper disposal of the filtered materials to ensure fibers are not released into the environment.

Innovation throughout the scientific community has been growing with new devices to capture and monitor macro- and microplastics. Although devices designed to clean up plastic pollution may regionally useful, they do not address the root cause of the problem. However, technology that can monitor and model microplastics are extremely useful in identifying pollution hotspots and focusing monitoring efforts to collect reliable data.

In addition to technological innovation, there have been some impressive community programs that have tried to address plastic pollution by creating community reuse programs to eliminate single-use plastic items. The ReThink Disposals Program,[23] designed and tested by Clean Water Action, and the Vessel Works Program,[24] are two examples of new systems that can be set up in communities to reduce single-use plastics in the food and beverage industry. ReThink Disposables works with companies and government agencies to replace single-use plastic items with durable reusables. Vessel Works is a free reusable stainless steel to-go cup service for cafes and their customers. Consumers sign up to begin using Vessels instead of paper coffee cups, using their Vessel throughout the day and returning at a participating cafe or return kiosk.

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23 https://www.cleanwater.org/campaign/rethink-disposable

24 https://vesselworks.org/

Table B-3. Innovations to prevent, capture, and remove microplastics.

Innovation: Addressing Microplastics		
TYPE	*DESCRIPTION*	*EXAMPLES*
Filtration for Washing Machines	Several filtration systems are on the market that filter out microplastics before the water enters the wastewater system, including Filtrol, Lint LOV-R, and others	https://filtrol.net/, http://www.environmentalenhancements.com/Lint-LUV-R-about-luv-r.html
Microfiber Catchment Tools for Laundry	New tools are on the market to help reduce microfibers from entering the wastewater systems, including the Cora Ball and Guppy Friend	https://coraball.com/, http://guppyfriend.com/en/
Textile Design	Steps being explored to modify textile design to reduce shedding. Alternative materials are being explored and evaluated.	Take back programs, new fabrics
Microplastic Monitoring Devices	New equipment designed to monitor microplastics more efficiently, such as in situ automated microplastic sensors.	https://www.mantaraysampler.com/
Trash Interceptors	A trash interceptor is a device aimed to collect and remove floating debris, including microplastics, including Mr. Trash Wheel used in the Inner Harbor in Baltimore and Seabin, and more recently a new technology called Bubble Barrier.	https://www.baltimorewaterfront.com/healthy-harbor/water-wheel/ https://www.seabinproject.com/ https://thegreatbubblebarrier.com/en/