RIVER PLASTIC POLLUTION

Considerations for addressing the leading source of marine debris

BENIOFF OCEAN INITIATIVE

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EXECUTIVE SUMMARY

Ocean plastic pollution is a global phenomenon widely recognized as a threat to marine ecosystems and organisms, as well as human health and wellbeing. However, recent research has demonstrated that rivers are the conduit for the vast majority of ocean plastic pollution worldwide, meaning that terrestrial plastic waste is finding its way to oceans via rivers. This is largely due to the ubiquity of single-use plastic, which is frequently mismanaged and therefore at risk of washing into watersheds, rivers, and eventually the ocean.

Examples of river plastics clean up efforts. Top-left: Mr. Trash Wheel, Baltimore, Maryland (Clearwater Mills); bottom-left: garbage collection boat on Pearl River in Guangzhou (Wiki Commons); right: Elastec boom (Elastec).

Rivers therefore provide an ideal opportunity for intercepting plastic pollution before it reaches the ocean. Here we review the state of the science regarding river plastic pollution on a global scale, including estimates of the volume of plastic pollution that enters the ocean from rivers each year and the environmental, social, and political drivers of that flux. We review the wide range of available technologies and collaborations that can be used to physically intercept plastic pollution in rivers, using successful case studies to illustrate possibilities. We also discuss the critical environmental, social, and political characteristics of a river that must be taken into account when designing a river plastic pollution intervention strategy, and the importance of outreach and communication in empowering communities to reduce plastic waste inputs into a river on multiple scales. Lastly, we emphasize the potential importance of river plastic pollution interventions in mitigating further ocean plastic pollution and suggest a global call to action.

PROBLEM:
RIVER PLASTIC POLLUTION

Concerns over plastic pollution in oceans and waterways have grown immensely in recent years. This increase in awareness parallels increases in scientific understanding of the magnitude and universality of the problem of plastic pollution. Plastic pollution is now found throughout the ocean, from the shores of remote islands to Pacific gyres, the ocean floor, arctic sea ice, and as significant proportions of beach sands[7,50,12,22].

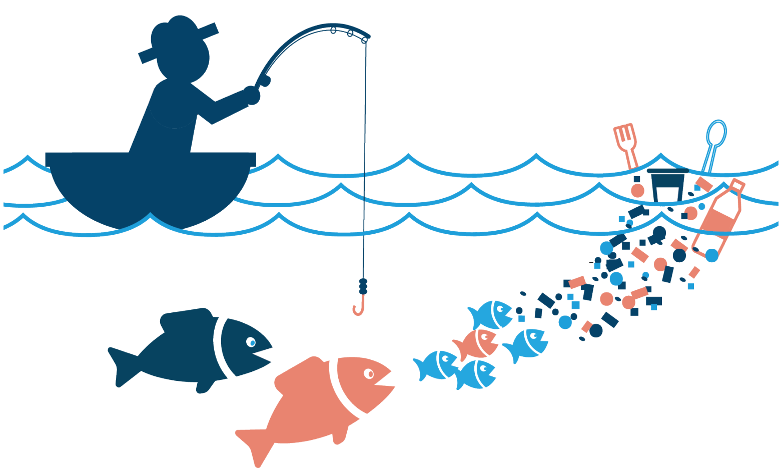


Figure 1. Ocean and river plastics affect humans through food, recreation, and other means.

Almost 700 ocean species are negatively impacted by marine debris, the vast majority of which is plastic; these species range from seagrasses and algae to fur seals and turtles, and 17% of these species are categorized as threatened by the IUCN[25]. Plastic pollution has also been found to impact human lives in increasingly diverse ways, with plastic particles recently documented not only in seafood but also in tap water, sea salt, beer, and even (and perhaps inevitably) human feces[60,37,53] (Figure 1).

New research provides an improved view of how plastic pollution travels through ecosystems and enters the ocean. Only 20% of ocean plastic comes from ocean sources (e.g. abandoned fishing gear), while 80% comes from sources on land, plastics which are thrown or washed into rivers that then drain into oceans[41]. Total estimates of river plastics entering ocean environments are variable, ranging from 0.48 to 12.7 million metric tons of plastics entering oceans from rivers and coastal zones in one year, a mass equivalent to approximately 5,000 to 125,000 blue whales[34,40,57,65]. Variations in estimates of how much land-based plastic ends up in oceans is driven by climatic, physical, and social factors.

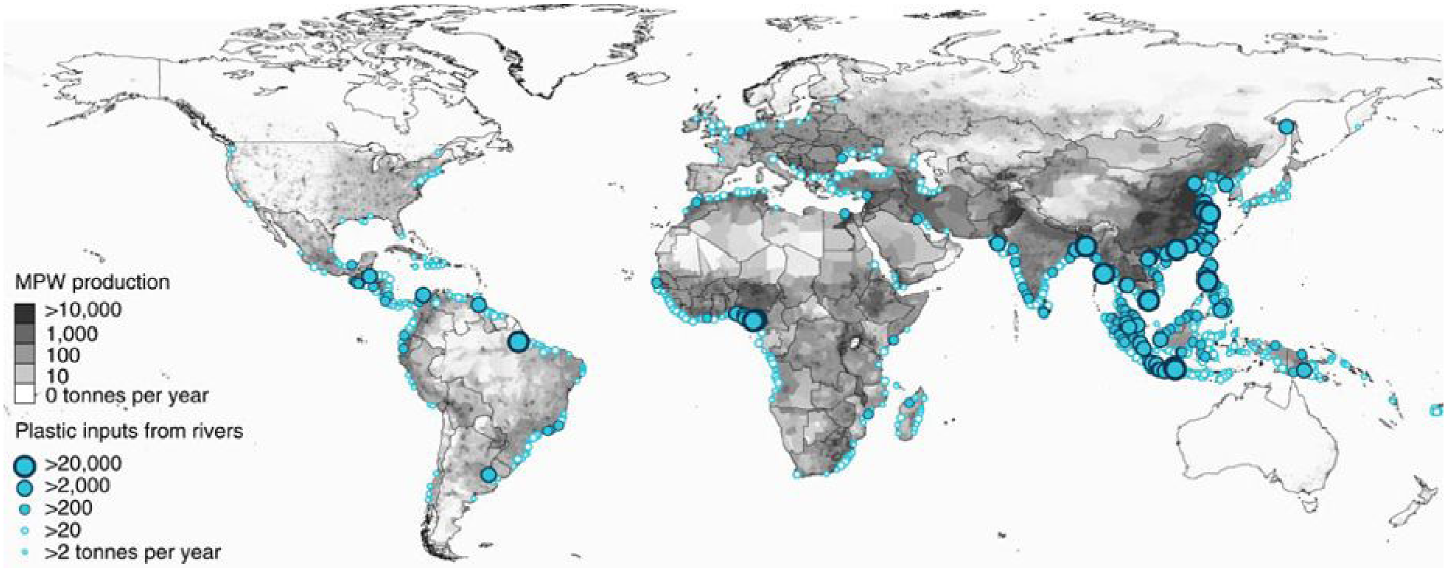


Figure 2. Map of river plastic emissions from coastal communities and catchments, from Lebreton *et al.* 2017[40].

Research to date suggests that the majority of this plastic pollution comes from only a handful of rivers worldwide, though more research is needed to clarify these estimates. What is clear is that for many reasons, volume of plastic emissions is not equitably distributed across the globe, with some regions (and in some cases individual rivers) identified as particularly high plastic emitters (Figure 2). It is thus well-documented that rivers present opportunities for strategic intervention in addressing the global plastic pollution problem. We assess the current state of the science on river plastic pollution and its efflux to oceans and propose research agendas to continue illuminating the problem of river plastic pollution. In all instances it appears that integrating multiple data streams on a given river (biological, physical, and social characteristics that influence plastic influx and flow) will likely be essential in improving empirical assessment of river plastic flux as well as informing best practices for possible intervention strategies. Additionally, we review existing technology options to capture and reduce river plastics pollution.

Addressing the global problem of plastic pollution will necessitate deployment of diverse interventions, tailored to the equally-diverse environments in which river plastic pollution is a problem. We highlight in this report the potential contribution that river plastics capture systems could make to addressing this issue. However, we emphasize that implementing plastic capture by itself is a strategy that is wholly insufficient to stop plastic pollution, and is arguably less impactful than development of systemic policy changes to curb plastic pollution, replacement of single-use plastics with cost-effective alternatives, changes in personal and population-level use behaviors that reduce plastic demand, and improvements in plastic waste management.

Top-left: Recycling bins (ProjectManhattan, Wiki Commons); top-right: Reusable bottles (Evita Ochel, Pixabay); bottom-left: river cleanup (Paige Bollman, Flickr); bottom-right: Charleston River sweep (Juan Pinalez, Wiki Commons)

Thus, while we recognize that there is great value in river plastic capture as part of a portfolio of near-term actions to combat plastic pollution, we propose that the goal of a successful river plastic intervention strategy should be to make the plastic capture portion itself unnecessary. A truly successful intervention strategy should leverage the data (volume, brand-audits of intercepted plastic; etc.) to illustrate the story of successfully-captured river plastic waste, to raise public support for change through several channels: public policies addressing plastic production and use, infrastructure to improve plastic waste management, reuse of plastic products to reduce disposal, and ultimately reduction of plastic product use when possible. In this way, a river plastic intervention strategy provides the immediate benefit of reducing plastic emissions to the ocean, but also the crucial longer-term service of ameliorating the root causes of plastic pollution production.

STATE OF THE SCIENCE

What we know

Here, we summarize the state of the science regarding river plastic pollution and its output into global oceans. Importantly, we focus on macroplastic (>5mm in size) pollution[9]. While microplastic pollution is an extremely important topic in ocean plastics pollution, the processes by which these plastics reach the ocean are significantly different. Macroplastics generally enter waterways via mismanaged waste (of which up to 80% is plastic[7], though this percentage is highly variable and as low as ~10%[34]). Microplastics, by contrast, originate from secondary degradation of macroplastics, runoff of road debris, or from personal products like exfoliators and synthetic fabrics that can shed microplastics[9]. What is more, the volume of research on marine microplastics far surpasses that on either macroplastic pollution or plastic pollution in freshwater environments[8].

Research efforts on river plastics emissions use a mix of methods to estimate the global influx of plastic pollution from land to rivers, and eventual efflux to the ocean. Despite differences in approach, each study identifies regions (from countries to individual watersheds) with the largest potential river plastic pollution efflux. In addition, they collectively determine that the volume of river plastic pollution is driven primarily by spatial, temporal, and environmental landscape characteristics, with the most volume occurring near urban centers and after rainfall events.

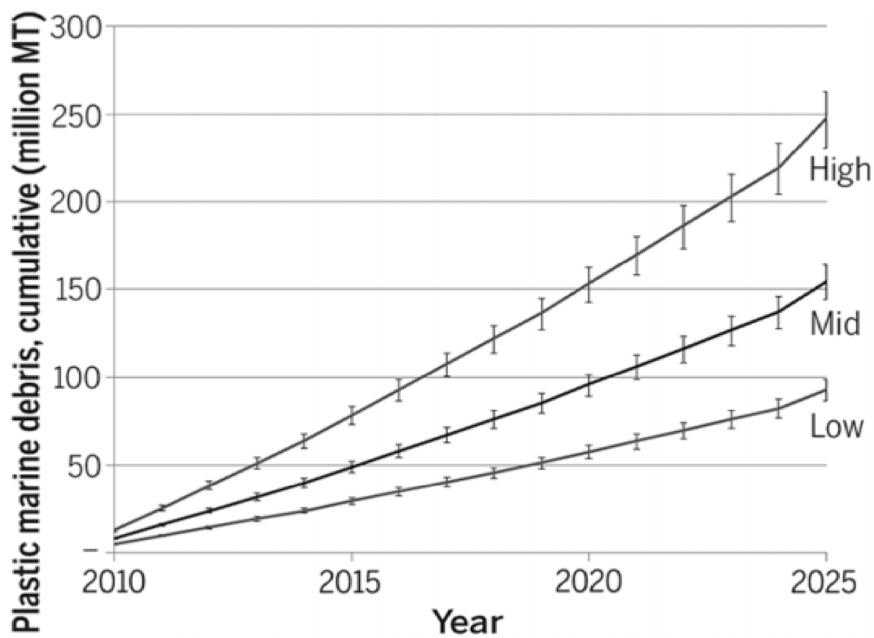


Figure 3. Estimated mass of plastic marine debris input into the ocean by coastal regions in 192 countries, assuming low (15%), medium (25%), and high (40%) conversion from mismanaged plastic waste to marine debris. From Jambeck et al. 2015[34].

A 2015 study by Jambeck et al. used a land-based modeling approach to estimate global volume of plastic pollution exported by rivers[34]. After assembling data on annual per capita mismanaged waste from 192 coastal countries, they predicted how much mismanaged plastic has the potential to reach the ocean via rivers or coastal runoff. By relying on population growth projections, they demonstrated the scale of probable increase in land-sourced ocean plastic pollution over time (Figure 3).

They asserted that 4.8 to 12.7 million tons of plastic waste flows into global oceans, and that by 2025 this number would increase by an order of magnitude. Additionally, they estimated that about 83% of the global total of mismanaged plastic waste with the potential to enter the ocean via rivers or runoff came from 20 countries.

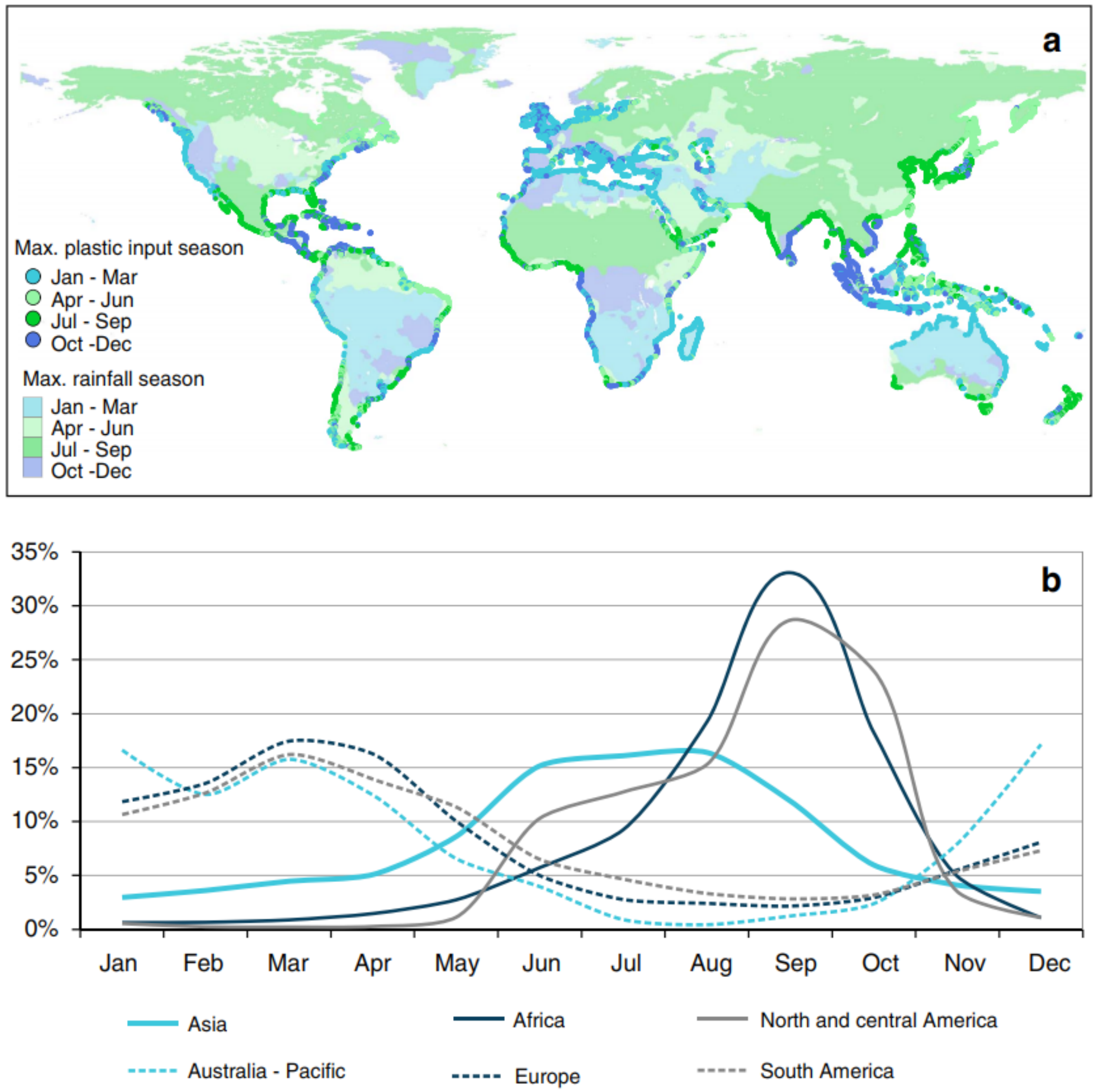


Figure 4, from Lebreton et al. 2017[40]:

a) Map illustrating dramatic seasonality of river plastic pollution inputs to the ocean, and the distinct linkage between climate and weather events and plastic flux.

b) Demonstration of differences in this seasonality by continent, with plastic flux peaking on average in those months with highest rainfall.

Lebreton et al. (2017) expanded this land-based modeling method by explicitly estimating the mismanaged plastic waste of over 40,000 individual watersheds, and then estimating the potential flow of this waste downriver to the ocean using calibrations from existing data on surface-water plastic concentrations in 13 rivers[40]. Importantly, this method included consideration of watershed characteristics like topography, dams, and other features that might influence the flux of plastic waste from rivers to the ocean. This model produced a more conservative estimate of 1.15 to 2.41 million tons of plastic waste (both micro and macro) entering the ocean from watersheds per year. Notably, most of the yearly plastic flow into oceans occurs between May and October, emphasizing that rainy seasons in regions that produce the most mismanaged plastic waste significantly influence temporal patterns of river plastic flow (Figure 4).

Schmidt et al. (2017) compiled existing data sets on concentrations of plastics found suspended in rivers (both micro and macro)[57]. By combining these data with data on river flow, they calculated plastic discharge rates for each river in the data set. They estimated total global plastic input from rivers to the ocean by applying these results to a model that integrated catchment population data for almost 1,500 catchments that empty into the ocean with estimates of the mismanaged plastic waste produced in each catchment. By then comparing these projections to the observational data on plastic concentrations in rivers, the authors calculated a "plastic delivery ratio," a conversion that reflects the proportion of mismanaged plastic waste that ends up in rivers. They estimated that 0.41 to 4 million tons of river plastics flow from rivers into oceans per year, and demonstrated a direct relationship between river size, population size, and flow of plastics to oceans.

Macroplastic suspended in a river (Pixabay).

Lebreton and Andrady (2019) assessed global data on mismanaged plastic waste, estimating increases in mismanaged waste generation under three scenarios: business-as-usual, increased waste management, and increased waste management plus decreased plastic production[39]. The assessment was conducted on a fine (1 km^2) spatial scale, which allowed for the consideration of watershed size, municipality size, and points of development (e.g. roadways) where size- or country-dependent differences in mismanaged plastic waste may be significant. They estimated that 60 to 99 million metric tons of mismanaged plastic were produced in 2015, and that this number could triple by 2060 under a business-as-usual scenario. Notably, this increase is not evenly distributed across the globe, depending on a region's demand for plastics as well as its population. Existing waste management infrastructure, rapid development, and rapid population growth contribute to the projected increase in global plastic pollution in different but important ways, and region-specific methods to prevent increases in plastic pollution will differ depending on which factor is driving the increase. Their projections also indicate that over 90% of plastics that can pollute the ocean travel via rivers, not by coastal runoff or direct input, again highlighting the significant opportunities for plastic pollution intervention in rivers.

These studies identify the top most-polluting countries (and even rivers) in the world as generally located in Asia, with several in Africa[34,40,57]. While river plastic pollution is a significant problem worldwide, there are many potential reasons for this apparent regional bias: prevailing climate, watershed size and proximity to urban centers, overall population, population growth rate, per capita plastic demand and plastic waste production, existing infrastructure to successfully manage incoming waste flows, and historic and current practices of exporting waste from developed to developing economies, among others. Countries that experience a disproportionate contribution to global river plastic pollution face challenges in more than one of these areas. For example, China and India together yield more than one third of the world's mismanaged plastic waste pollution, thanks to high proportions of waste mismanagement in general, large and growing populations with concomitant increases in plastic production demand, significant rainy seasons, a history of significant global plastic importation, and other factors that likely impact plastic efflux from their rivers[10,39,40].

Shanghai, China (Steven Yu, Pixabay)

In addition to temporal influences like seasonal rainfall as drivers of high river plastic efflux in these regions, an important spatial driver is the proximity of cities to rivers. Indeed, a major factor in plastic input into rivers is human population[57]. As cities have historically formed along rivers, it follows that human population (size and density) is highest along rivers[29,38]. In 2018, seven of the top ten largest cities in the world were in Asia, with most of the world's fastest growing cities in Asia and Africa[64]. Trends in population density and growth potentially provide further mechanistic explanation for the large proportion of global plastic pollution coming from these continents' rivers.

What we don't know

Despite the uptick in recent research on the issue, there is a lack of standardized research on macroplastics pollution in freshwater systems. The current estimates of plastic input from rivers are derived from extensive modeling efforts that combine data from different sources, and often include a mix of micro and macroplastic data. However, there are few published reports of direct observational data describing rivers' macroplastic pollution and flow[8]. What data are available have been collected using a variety of methods, which are often labor- and resource-intensive. Lack of standardized data collection methods or baseline data for river plastic pollution and flow highlights how difficult it is to make global generalizations about river plastic pollution and flux to oceans. In response, scientists are championing the formation of standardized methods to measure river plastic concentration and flow.

Most recently, van Emmerick et al. (2018) proposed a simple monitoring method for assessing volume and flow rate of surface-level (e.g. floating) macroplastic pollution in rivers[66]. By conducting cross-sectional visual profiles of plastic in rivers, taking samples of plastic pollution at those sites to calculate mass, and accounting for river hydrology, it is possible to calculate the mass and flow rate of plastic pollution in rivers, and to use these values to determine the efflux of plastic into oceans from any river that is monitored. Importantly, this method is relatively low-cost, and is not resource intensive: as visual transects across rivers can be taken using observers on bridges, drones, or mounted cameras, there is no need for expensive boats or monitoring equipment. Indeed, this method could utilize existing citizen scientist networks, like those of the Ocean Conservancy's global International Coastal Cleanup[24].

If such standardized methods for surveying river plastics are to be successful, they will require implicit acknowledgement of the significant variation in hydrological, biological, and social characteristics of individual rivers (and indeed even at different sites along the same river). Thus for an individual river there should be a 'to-do' list of data collection tasks that must be completed to most effectively measure plastic emissions and successfully inform the design of a river plastics intervention strategy. Such tasks include:

- Empirical data collection to determine baseline plastic flow for the river
- Assessment of intensity and frequency of events that introduce variation in plastic flow
- Identification of site-specific factors that moderate plastic flow, such as:
    - Physical: dams, wetlands, river flora and fauna
    - Social: local plastic use, disposal practices, waste management access and quality
- Identification of possible fates of plastics as they make their way through rivers (e.g. float at the surface, retained in sediment-rich river bottoms, trapped in the water column)
- Identification of the proportion of a given river's plastic pollution that reaches the ocean

For social characterization of rivers, data collection methods from social science fields could be leveraged to great effect[11,16,56]. Ideally, once these data are collected, an integrated characterization of the biology, hydrology, and sociology of a selected river can be used to design a unique strategy.

LANDSCAPE OF RIVER PLASTIC CLEANUP TECHNOLOGIES

There are many potential intervention tools presently on the market or being developed for river plastics cleanup efforts, and indeed already in place in some sites. Here, we review a sampling of current tools (Figure 5) that could be utilized alone or together in designing a river plastics intervention strategy. This is not intended to serve as a comprehensive accounting of all such intervention strategies, but rather a survey of major classes of intervention. Importantly, it is vital that the tool or tools chosen for a given strategy take into account the social and biophysical characteristics of a river that might contribute to successful plastics capture.

Hand collection	Boats	Booms	Receptacles	Innovations and method combinations

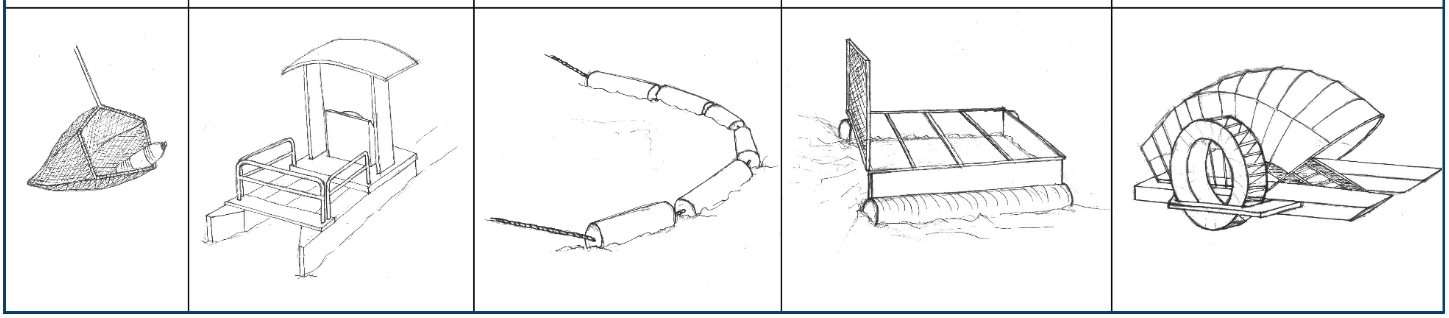


Figure 5. Categories of river plastic cleanup tools

Manual collection

Pollution in Indonesia's Citarum River, 2009 (Wiki Commons)

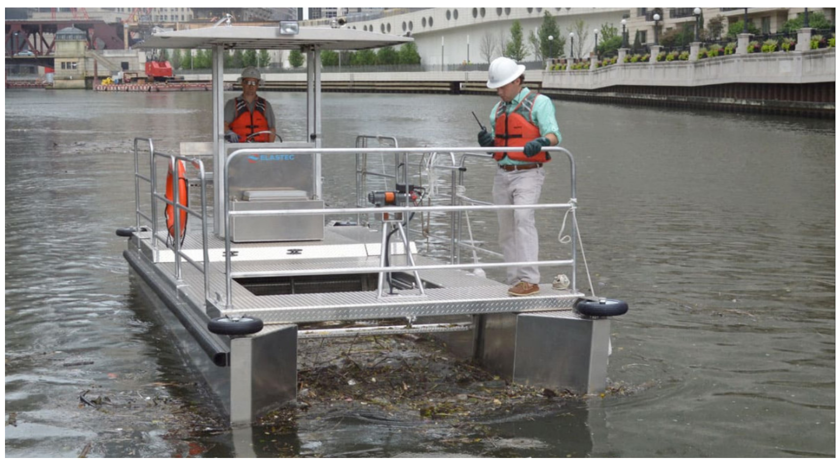
The most intuitive suite of methods for capturing plastic pollution in rivers involves manual collection of plastics that float downstream. For example, in early 2018 Indonesia deployed a military cleanup operation on the Citarum River, a vital source of irrigation and water needs for 27 million people[31,59]. With the river acting as a waste receptacle for households and industrial manufacturing plants alike, over 500,000 cubic meters of trash (a volume equivalent to 200 Olympic swimming pools) flows downstream per year. Seven thousand soldiers, deployed in units to sections of the river, hand-collect this trash with nets by traversing moveable barges. In the capital, Jakarta, over 4,000 workers are employed in removing litter from rivers and other bodies of water[70]. However, continued influx indicates that plastic use and waste management infrastructure and are entrenched challenges requiring long-term strategies.

Left: Anacostia River cleanup in Washington, DC (Gwen Bausmith, Wiki Commons); Right: River sweep in Charleston (Juan Pinalez, Wiki Commons).

Manual collection of river waste is occurring elsewhere, at scales large and small. Companies like the for-profit charitable organization 4Ocean prioritize local job creation via manual collection as a pillar of their plastic cleanup efforts[72]. In August 2018, over 20,000 volunteers participated in a cleanup event at rivers and beaches all over Thailand[49]. Smaller-scale or one-time efforts are underway in cities all over the world, including the United States[13] and Europe[45,61]. The scale of public involvement in these and other cleanup events demonstrates that there is already significant awareness of and personal value in river plastic pollution solutions.

Boats

The next step up in complexity is to integrate boats into river plastic pollution cleanup efforts. There are several varieties of boat specifically designed to skim plastic pollution from river surfaces, which are deployed in settings ranging from nuclear waste facilities to major municipalities[18,15]. Cleanup boats operate with skimmers or conveyor belts to collect trash as they move through the water.



Work boat that can collect floating trash in rivers. (Elastec)

Many of these options are small and easy to maneuver, and are thus practical options for river plastic cleanup efforts. Indeed, some have successfully been deployed in several rivers in the United States already to varying degrees of success. For example, custom catamarans with skimmer baskets cruise the Chicago River collecting effluent trash from the city's municipal sewer system[21].

Booms

Other tools were originally designed for different cleanup operations, but have since been successfully utilized for river plastic. Booms developed to aggregate oil from spills can also aggregate plastic pollution traveling downriver. A variety of booms, from large barriers that sit in coastal waters collecting plastic as it flows out of river mouths, to smaller ones that redirect plastic waste into catchments or dumpster-like baskets, have been successfully deployed in rivers[19]. Often, these booms and collection devices can be tailored to account for river size and site- or season-specific weather events, like storms, that result in large fluxes of water and thus plastic pollution.

This boom collects surface and submerged trash, litter, and large floating objects in rivers, reservoirs, oceans, and lakes (Elastec)

Receptacles

While booms divert and aggregate plastic pollution, it still needs to be removed from rivers. In many cases, a series of booms will direct plastic flow into a collector of some kind, either passive[20] or actively powered by water flow or external power sources[69]. Some are put in place temporarily to deal with post-storm plastic flow, while others are long-term installations. Since their deployment in 2014, for example, the Inner Harbor Water Wheels of Baltimore Harbor have collected almost 1,000 tons of river debris from the Jones River watershed, a 150 square kilometer region of Baltimore County[69].

"Mr. Trash Wheel" water wheel, Baltimore, Maryland (Clearwater Mills)

Small-scale innovations

Myriad other creative inventions have entered the plastic cleanup market, and could be deployed in the service of river plastic pollution intervention alongside large-scale tools like those discussed above. Seabins look like floating trash cans, but are powered by pumps that pull water from their open tops through a filter bag at the bottom to collect plastic particles[58]. Designed to be placed in calm waters near a power source (a dock or a marina, for example), Seabins can collect up to 20 kg of waste per deployment, from large to small plastic particles. A larger version of this concept is the Marina Trash Skimmer, a dumpster-sized pump-and-filter tool that is also designed to attach to docks. It is has been highly successful in California, Oregon, Hawaii, and Texas, demonstrating its potential for deployment along rivers[43].

Combination bin and boom system that captures floating trash as it travels downriver (Elastec)

Often plastic intervention strategies in rivers integrate a combination of several individual tools. For example, collection receptacles are most often used in conjunction with booms, which guide plastic waste as it flows downriver into the anchored receptacle. Another, high-profile example is 4Ocean, which funds their plastic waste cleanup efforts with the sale of recycled beaded bracelets. At their launch, the company relied primarily upon the combined power of manual collection and boats by creating job opportunities for fishermen to collect plastic along coastlines and in the ocean[72]. In 2018, they launched a new system that integrates more tools to tackle river plastic pollution at river mouths: a custom-length boom traps effluent plastic at the mouth of the river as it flows downstream, where it is held until it can be collected with nets by a fleet of small boats deployed from a larger vessel. These boats deliver their hauls of plastic to the larger vessel, which is outfitted with cranes to lift the heavy bags of plastic waste, where it is stored until it can be delivered to a waste management facility[73].

What to consider?

Due to the breadth of available tools, and vital, location-specific factors like feasibility and cost, the design of any given river's plastic intervention strategy will require a thoughtful combination of tools. Many river characteristics, like flow rate, width, and depth must be considered when deciding which tools to implement (Figure 6). Rivers that flow through wetlands, for example, will likely need a different combination of tools than those that flow through culverts or under urban areas. Additionally, social characteristics of a site should be considered when identifying the best tools and technologies for a river plastic intervention strategy. Methods like manual collection could provide municipal employment opportunities (see 4Ocean), while large, highly-visible tools like water wheels might provide significant outreach and education opportunities (see Baltimore's harbor-based water wheel).

Figure 6. Many factors should be considered when seeking a river plastic itervention, including location, river dynamics, costs, surrounding infrastructure, and political landscape.

It is of the utmost importance to acknowledge the significant barrier of cost that available technologies for river plastic intervention may pose. Successful intervention strategies will ultimately consist of the combination of methods and tools that is logistically and financially feasible in a given location.

POLITICS AND POLICY OF RIVER PLASTIC INTERVENTION

The political landscape of a river should influence, facilitate, and shape a river plastic intervention strategy. These landscapes are likely to be complex and unique to each river, particularly those that run through multiple municipalities, states, or even countries. In all cases, there will almost certainly be multiple managers for the river in question and the waste that runs through it. Here, we discuss several cases where very different river cleanup strategies would need to be designed to account for place-based social complexities.

Plastic pollution in the Mekong River, Vietnam (Shutterstock)

The Mekong River is the world's twelfth longest, at 4,350 km, with a watershed that stretches across about 800,000 km^2. It flows through China, Burma, Laos, Thailand, Cambodia, and Vietnam, supporting 65 million people in these different countries, thus making any potential river plastic intervention effort an issue of international cooperation. The Mekong River has been consistently identified as one of the top ten plastic-polluting rivers identified in recent publications: each year, about 22,800 cubic meters of plastic flows into the Mekong, with around 6,000 discharging into the ocean[40].

Acknowledging the need for coordinated management in 1995, the governments of Laos, Thailand, Cambodia, and Vietnam created an intergovernmental organization dedicated to a sustainable future for the river: the Mekong River Commission, or MRC[46]. Its goal is to provide a strong, international legal foundation for promoting and coordinating sustainable development and management of this water resource. The MRC is collecting baseline data on river health at different points along the river, data that could inform river plastic intervention designs. Despite the cooperation demonstrated by the formation of the MRC, challenges remain; for example, each country involved may prioritize different outcomes in river cleanup efforts, making the cohesive design of an intervention strategy for the Mekong difficult. Despite the many challenges inherent to international cooperation over a shared resource, the MRC's efforts suggest that it is possible for multiple governments to support cleanup efforts in a single, internationally-flowing river.

Complicated politics are not reserved for rivers that flow internationally. In the United States, bodies of water are regulated by the Environmental Protection Agency's (EPA) 1972 Clean Water Act (CWA)[71]. While this policy has been hugely successful in cleaning national waters, there remain challenges in coordinating state and federal government jurisdictions simultaneously. The CWA is what allows the EPA to set national limits on how much pollution (including plastic) is allowed in waterways, though states can apply to administer their own pollution control efforts[26]. Some states and municipalities have pushed back against what they perceive to be federal overreach in setting limits on and controlling water pollution. Disagreements between federal and state governments regarding the implementation of the CWA have created tension, and subsequently lawsuits, over which level of government should control a given river, point pollution source, or cleanup effort[54].

Mississippi River in Minneapolis, Minnesota (formulanone, Wiki Commons)

What is clear from these two examples is the potential for politics to complicate the creation of river plastic intervention strategies. They also point out the necessity of working within each site's unique political parameters to succeed, and specifically the need for solid partnerships with essential political actors. For example, a successful river plastic intervention strategy in the Mekong would likely require dedicated cooperation with the MRC. A successful river plastic intervention strategy in the Mississippi River, which flows through 124 cities and towns in ten states, would likely require cooperation with an organization like the Mississippi River Cities and Towns Initiative (MRCTI), an organization that empowers local mayors to collectively reach the federally-mandated clean water statutes[48].

COLLABORATIONS

As seen in the examples of the MRC and MRCTI, cooperation with political bodies is likely to be an essential step in designing successful river plastic intervention strategies. However, collaborations with other actors is likely to be another important step[1,2,314,52,55,63,72].

Community partnerships: Baltimore's Waterfront Partnership, a case study

Because of the unique river characteristics (social, biological, physical) in a given location, collaboration on municipal or other community scales is key to designing successful river plastic intervention strategies. Here, we discuss the community partnership to address river plastic pollution in Baltimore Harbor as an example of successful collaboration between different community actors aiming for the goal of plastic pollution reduction in a common resource.

Baltimore Harbor, Maryland (Wiki Commons)

Baltimore's Waterfront Partnership is a collaborative group of city officials, non-governmental organizations, small waterfront businesses, and private property owners and citizens. The partnership has committed to a large suite of harbor cleanup efforts, public education and outreach events, and policy changes that benefit the health of the harbor and its usability for residents. The far-reaching benefits of a diversity of stakeholders is clear: the partnership's goals include public outreach and education campaigns in Baltimore public schools, identification of faulty municipal sewer systems that contribute to plastic pollution in waterways leading to the harbor, regular surveillance of pollution and its sources to the harbor, and promotion and implementation of policies that ban certain single-use, highly-polluting plastics like polystyrene foam[68].

Side view of "Mr. Trash Wheel", Baltimore, Maryland (Clearwater Mills, LLC)

Importantly, the partnership and its programs (like the 2011 Healthy Harbor plan) include a multifaceted river plastic cleanup strategy. In 2014, a trash wheel was deployed at the junction of the Jones Falls River and the harbor to intercept waste that flows into the harbor from the 29 km-long river. Booms corral incoming waste and direct it toward a flow- and solar-powered wheel outfitted with a conveyer belt, which deposits the collected waste into a dumpster. The wheel itself is hugely popular, with a charismatic appearance and vibrant representation on social media[36]. In addition to being popular with Baltimore Harbor visitors, it has proven highly successful, and in 2016 another trash wheel was installed. Together, the two have amassed almost 1,000 tons of trash, including approximately 750,000 plastic bottles, 581,000 plastic grocery bags, and 974,000 plastic snack bags[69].


"Mr. Trash Wheel", Baltimore, Maryland (Clearwater Mills, LLC)

Successful reduction in plastic pollution by the Baltimore Waterfront Partnership has played a role in improving ecosystem health, recreation, industry, and tourism. This improvement has resulted in greater public engagement with pollution issues in the harbor, and ultimately in municipal actions like provision of lidded trash cans to all Baltimore residents, funding to repair faulty sewer infrastructure, and a city-wide ban on single-use polystyrene[4,69].

PUBLIC INVOLVEMENT

While emerging research indicates that river plastic pollution is one of the most impactful contributors to ocean plastics, and a problem in its own right, river plastic intervention strategies should not only include physical removal but also efforts to stem the tide of pollution at its source.

Social, infrastructural, and policy changes regarding plastic consumption and disposal are necessary to curb the flow of plastics into rivers. Indeed, the physical capture of pollutant plastic in rivers should be considered a short-term solution in deference to long-term changes that reduce or eliminate plastic influx. Creating opportunities for outreach and communication on the detrimental effects of river plastic pollution with industry leaders, policy makers, and individuals could facilitate these long-term changes, and therefore must be essential parts of river plastic intervention strategies (Figure 7).

Practitioners provide outreach events on the dangers of river and ocean plastic pollution for the community near the proposed intervention site to better contextualize the need for a river-based intervention at the site and elsewhere.

Practitioners provide opportunities to involve constituents in active cleanup efforts, creating opportunities for employment and/or a vibrant community of volunteers.

With access to information on a site's plastics problem, constituents feel a greater connection to that site and a sense of responsibility for it. Thus, public-facing communication will foster community around the river plastic problem[32].

Feelings of responsibiity will likely translate to changes in personal behavior in plastic use and disposal leading to community-wide support for and public pressure to positively change norms regarding plastic use and waste management[44,47].

Figure 7. Examples of public engagement and potential outcomes

Community-wide shifts in plastic use and management norms can engender policy and infrastructural change, as public pressure provides significant influence for improved environmental policies[5,35]. Indeed, lack of community engagement with the problem of macroplastic pollution in aquatic environments, born from a demonstrated lack of information about it compared to ocean and microplastic pollution, could be a driving force behind the lack of policies designed to remedy it[6].

CALL TO ACTION

As discussed throughout, a successful intervention strategy will depend on an individualized assessment of the target site's many social, biological, and hydrological features that collectively characterize its plastic pollution problem. The combination of tools (for both the physical interception and the communication and outreach portions) that will succeed will therefore be unique to the site's social and biophysical fingerprint. It is tempting to conclude that first steps at intervention should occur at the river or rivers that are the largest sources of plastic pollution. However, this perspective ignores factors that might make other, perhaps less-polluted rivers more attractive in prioritization. Indeed, selection of a river for intervention might be based not only on its plastic load, but place-based factors like constituent and local government support for an intervention strategy, suitability of the river's hydrology to installation of technology, consideration of potential impacts on wildlife, involvement of a local non-profit organization, and others.

Once a river is selected for an intervention strategy, baseline data should be collected to determine its starting plastic load and other relevant information regarding the river's pre-intervention state. Beyond baseline data collection, determining the priorities of a plastic intervention strategy before it begins will inform strategy design. For example, a given site might prioritize:

- Municipal job creation via plastic collection workforce
- High visibility of technology to promote public engagement
- Policy change regarding single-use plastic products
- Improvement of waste management infrastructure
- Maximum volume of river plastic pollution capture
- Brand audits on macroplastics collected to determine if and from where disproportionate plastic pollution occurs

It is probable that the goals at any site will be some combination of priorities like those above, which will in turn inform which suite of tools are most appropriate. A site whose goals include maximum macroplastic pollution collection, data collection on composition and branding of plastics collected, and large-scale community involvement or job creation might prioritize the implementation of manually-powered teams over more autonomous technologies for plastic collection, sorting, and data collection. A site prioritizing community involvement to generate public support for policies that improve local waste management or plastic pollution prevention may instead choose an approach that strategically installs a plastic capture technology to maximize visibility, and thus the opportunity to inspire the interest of the community.

Baltimore provides such an example, with its waterfront partnership's installation of plastic-collecting trash wheels. These innovative and visually-compelling tools have an active presence on social media, are the centerpieces to cleanup-themed community events, and have spurred the creation of opportunities for community members to engage with harbor cleanup efforts. Indeed, when data from the trash wheels revealed styrofoam containers were the second most common plastic collected from the Jones Falls River's outflow into the harbor, public pressure created the impetus for a city-wide ban on the containers[4].

Despite inevitable (and purposeful) differences in design and rollout, all river plastic intervention strategies will encounter the question of what to do with plastic pollution once it is collected. Rivers that flow across national boundaries (for example, the Mekong, the Ganges, the Amazon--all three included in recently-published lists of top plastic producing rivers) would require international agreement regarding which nation or coalition of nations accepts responsibility for any collected plastic waste. Rivers that flow between states or municipalities will face the same challenge on a within-nation scale. In all cases, plastic must be removed from the mismanaged waste category, by being diverted back into the waste stream to be properly managed: landfilled in closed-top sites, recycled physically or chemically, eliminated via methods like waste-to-energy[17], or other outlets.

In summary, those conservation practitioners and researchers looking to design and implement a river plastics intervention strategy must consider: what are the priorities and metrics of success for the river selected? Subsequently, what is the suite of techniques and technologies that will form a successful, unique, and place-based strategy? What data can and should be collected before and after strategy implementation to demonstrate that the most highly-prioritized goals are being met? Crucially, can the strategy be designed with the ultimate goal of reducing river plastic pollution inputs to zero, such that physical plastic interception is eventually phased out? These questions should be core to the design of river plastic intervention strategies to ensure that an individual river's character is carefully considered and incorporated, and that the strategy's ultimate goal is stemming the tide of plastic pollution to the river and not relying on capture as a bandaid fix.

Left: Shasta-Trinity National Forest cleanup (USFS); Center: Plastic sorting facility in Australia (Wiki Commons); Right: Potomac River cleanup (Airman Gabrielle Spalding, U.S. Airforce)

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