2023-11

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10.1016/j.oneear.2023.10.022
One Earth
Elsevier BV

One Earth

Commentary

Moving from symptom management to upstream plastics prevention: The fallacy of plastic cleanup technology

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https://doi.org/10.1016/j.oneear.2023.10.022

Plastic removal technologies can temporarily mitigate plastic accumulation at local scales, but evidence-based criteria are needed in policies to ensure that they are feasible and that ecological benefits outweigh the costs. To reduce plastic pollution efficiently and economically, policy should prioritize regulating and reducing upstream production rather than downstream pollution cleanup.

Addressing the plastics crisis

Plastic pollution accumulates in all environments, from the highest mountains to the deepest oceans.[1] Production is projected to triple by 2060, with plastic pollution increasing correspondingly under business-as-usual scenarios.[1] Plastics and other chemical pollutants are already outside the safe operating space for humanity, threatening critical Earth system processes related to climate and biodiversity, causing adverse impacts on human health, organisms, ecosystems, and biogeochemical cycles.[2]

In response, the UN Environment Assembly adopted a resolution (UNEP/EA.5/Res.14) to develop a Plastics Treaty by 2024. As the treaty negotiations progress, stakeholders debate how to prioritize different solutions including the prevention, reduction, management, and removal of plastics. From a scientific perspective, measures to reduce the production and consumption of virgin plastics are key to minimizing global pollution efficiently and economically,[3] yet scenario studies show that even if all available measures are implemented, the growth in plastics production will be too high to prevent further pollution entirely.[3]

Plastic removal technologies (PRTs), often framed as "cleanups," have been developed to mitigate pollution.[4,5] However, PRTs are associated with various concerns related to their technological challenges, environmental impacts, equity and justice, verifiability, market-based "greenwashing," and distraction from more effective solutions.[4–6] Verifiability relates to performance being scientifically proven. Questions of equity and justice relate to how they might allow the costs of polluting industries to be externalized onto communities with far less resources, agency, and responsibility for the design of hazardous and wasteful products and production levels. There are many lobbyists and advocates for the introduction of a new market for the sale of plastic offsets or plastic credits in relation to PRTs within the Plastics Treaty, analogous to the carbon credits' market in the context of climate change mitigation and with similar concerns. Advocates from plastic-producing states, brokers seeking to sell PRTs, and PRT manufacturers have become increasingly vocal in arguing that PRTs should be enshrined in global policy. While PRTs could be necessary in some local cases, such as heavily polluted harbors, beaches, and rivers, in a global context, PRTs should not be enshrined in a treaty for purposes such as plastics offsetting. There is no evidence that the net benefits of PRTs outweigh their environmental and economic impacts outside highly polluted areas.[4,5,7]

In this commentary, we address the feasibility and scalability of PRTs. First, we describe ecological impacts of different PRTs alongside ethical, political,

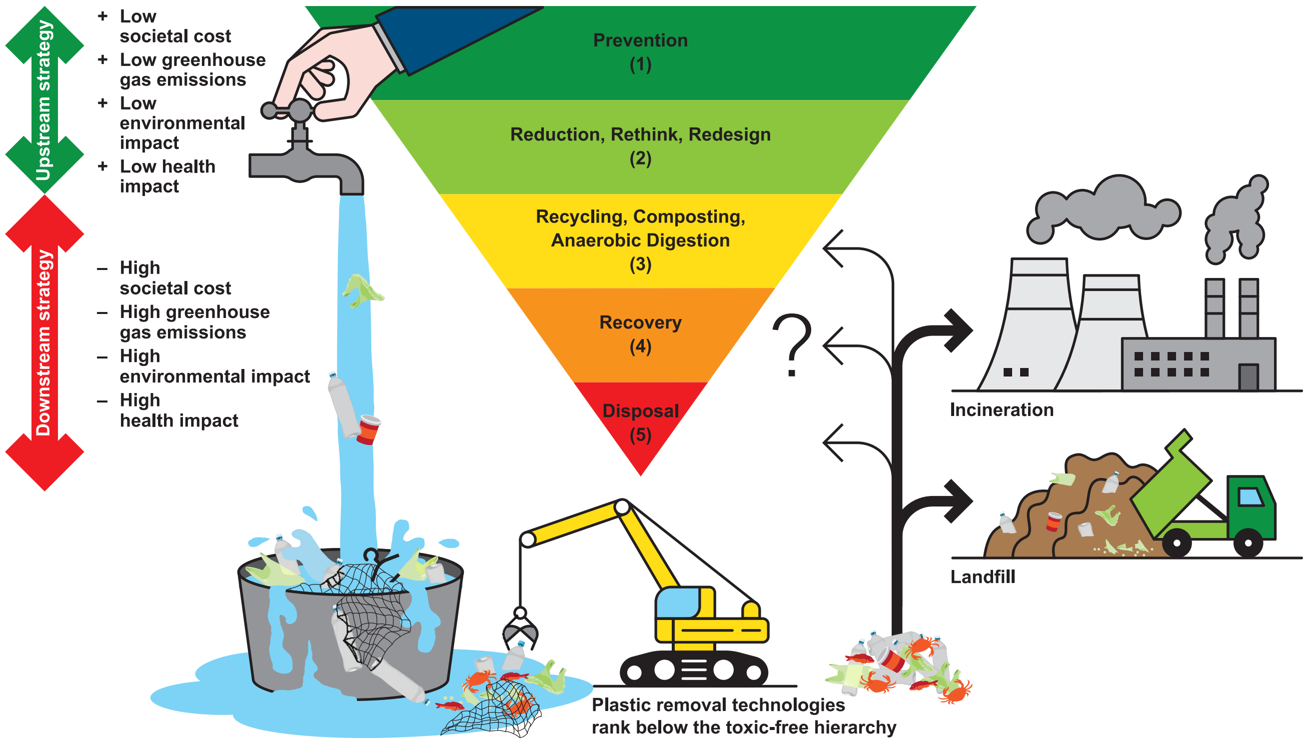

Figure 1. Toxic-free plastic pollution minimization hierarchy
Actions higher up the waste hierarchy decrease the need and scope for each of the more costly and potentially more harmful interventions further down the hierarchy including plastics removal: (1) Prevent and minimize production of non-essential and hazardous polymers, chemicals, and products according to time-bound reduction targets for plastic production. (2) Redesign products and distribution of goods to minimize plastics and their hazardous chemicals throughout the life cycle. (3) Recycle toxic-free high-quality materials from separate waste streams. (4) Extract valuable residual materials from mixed waste and discards from sorting processes (including chemical recycling of discards only from recycling). (5) Isolation of biologically stabilized residues. Plastic removal technologies rank below the toxic-free waste hierarchy as collected plastics likely feed into landfills, incinerators (bigger arrows), or recycling or recovery processes (smaller arrows). Goal 1 reduces the need for goal 2. In turn, goal 2 reduces the need for virgin materials and toxic chemicals, which supports goal 1. Goals 1 and 2 reduce the need for plastic pollution removal of polluted environments. Preventing plastic pollution has lower economic, societal, and environmental costs than managing and removing plastic (modified from Simon[8]).

and economic aspects. We argue that the priorities for the Plastics Treaty should sit higher up in the toxic-free, zero-waste hierarchy,[8] focusing on prevention and reduction rather than cleanup (Figure 1). For necessary removal efforts, a science-based accreditation system should be in place to verify the effectiveness of PRTs and minimize regrettable outcomes.

Technological challenges and environmental consequences

Removing plastics from the environment improves habitat quality and reduces the risk of interactions with biota, especially since growing amounts of plastic are estimated to break down into irretrievable smaller plastics that can be ingested by a wider range of species.[1] However, the ecological impacts of PRTs deserve attention, as they could affect biodiversity during collection and subsequent disposal in an era of accelerating extinction. Generally, unselective collection methods like sieving, raking, netting, or conveyors can alter habitats and trap organisms along with plastics, causing injury and bycatch mortality.[4,5,9] Manual collection selectively removes plastic but is labor-intensive and limited in scope. Currently, almost no environmental impacts assessments (EIAs) have been conducted for PRTs.[4,5]

Coasts

Beaches in high-GDP (gross domestic product) states and tourist areas are regularly groomed by raking or sieving vehicles, claiming to protect ecosystems. However, beaches are important ecosystems with habitat-forming plants and sediment-dwelling animals that feed birds and fish. Regular grooming can alter these habitats at landscape scale and cause mortality or injury to dune plants and invertebrates.[9] The concomitant removal of algal debris, which provide food and habitat for many animals, reduces beach biodiversity.[9] Ironically, award-winning beaches are subject to more grooming and thus lower biodiversity.[9] Regular grooming creates a biased public perception of low plastic pollution. Although it seems challenging to reconcile the demands of intensive tourism and conservation given economic priorities, policies favoring manual grooming, a lower grooming frequency, and exclusion of areas for recovery could relieve the pressure.[9]

Many harbors around the world use plastic-trapping technologies such as Seabins, which skim floating debris from the sea surface by pumping water into a bin device. A scientific evaluation showed that they capture trivial amounts of plastic (0.0059 kg day^{-1}) but substantial quantities of seaweeds.[7] For every four pieces of plastic, Seabins caught one organism, 73% of which were dead after two days.

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Five hundred Seabins would need to run continuously to keep a small harbor free of floating plastics.[7] With maintenance costs orders of magnitude higher than manual cleaning, half of the users surveyed stopped using Seabins.[7]

Rivers

Rivers are important carriers and reservoirs of plastic pollution. Riverine organisms are therefore likely to be affected by plastics as their oceanic counterparts. At least forty different types of PRTs are used in rivers and estuaries comprising booms, watercraft vehicles, bubble curtains, or receptacles.[6] Bycatch is affected by factors such as hydrology, species traits, plastic properties, and technology used.[6] Most riverine PRTs use non-selective technologies removing (potentially endangered) organisms, wood, and other natural flotsam that form important habitats for organisms. Nevertheless, environmental impacts are rarely assessed, probably for lack of policy.[6]

There are additional concerns with riverine PRTs. They only skim the water surface, missing much of the deeper plastics; devices located at river mouths do not remove plastics from riverine ecosystems themselves; removal efficiency can be low, with one estimate as low as 54%[10]; and, to significantly reduce plastics outflow to the ocean, thousands of rivers would need PRTs. A potentially more ecologically supportive alternative are stormwater traps, which retain large plastics closer to the point of release so they do not enter streams.

Ocean surface

Removing plastics from the ocean surface was popularized by The Ocean Cleanup (TOC), which made its name on the premise of using oceanic currents to passively clean the high seas' surface. After several iterations, TOC reverted to a net towed at slow speed for up to two weeks to capture plastics. This leads to significant bycatch and likely increases neuston (surface-dwelling organisms) mortality as plastics and neuston animals accumulate in the same areas in the North Pacific Convergence Zone.[11] These surface communities are important to the functioning of nutrient-limited ecosystems of the high seas but were not included in initial EIAs.[12] A single TOC device running for one year could impact 675 tons of zooplankton[5] along with sea turtles and sharks.

The floating plastics that TOC could collect globally constitute a minor fraction of plastics in the ocean. Even in ecosystems like the North Pacific Convergence Zone, plastics are distributed across the interior ocean and vast areas.[1,5] Collection efforts at scale would have to be enormous: 200 TOC devices running for 130 years would only capture 5% of the world's floating plastics[9] and result in significant CO_2 emissions as two large ships tow each device. Manual collection and renewable energy can avoid high mortality and emissions. The Ocean Voyage Institute works with sailors to fit GPS trackers to derelict fishing gear encountered on their journeys. The Institute's sailboats selectively retrieve the items, which totaled 150 tons in 2020.[13]

Seafloor

Many ocean plastics accumulate on the deep seafloor, which is notoriously difficult to access. Recent EU projects aspired to remove plastics from the seafloor using autonomous vehicles, robotic systems, and artificial intelligence.[4] Given the complexity of the task, such PRTs have a long way to go before they are technically mature[4] or feasible on a large scale, particularly in terms of operating costs.

Fishing-for-litter initiatives, in which fishers collect plastic debris during ongoing fishing operations followed by disposal in dedicated port reception facilities, reduce plastics on the seafloor at low additional effort and inspire behavior change among participants and potentially their peers. This could be a lever for change for a sector responsible for a major source of hazardous marine plastics.[1] Plastics-only trawling has not been widely pursued, probably because it is time-consuming, risky, and challenging, especially at greater depths and on hard grounds. As with bottom fishing, this practice likely causes significant bycatch mortality and damage to habitats. Plastic removal by divers could reduce shallow-water pollution but is limited in scale and depth and is risky.

Scale

The potential effectiveness of PRTs will continue to fall far short of the rapidly increasing scale and complexity of the problem as global plastics production increases. Worldwide, coastlines stretch for hundreds of thousands of kilometers. The ocean has a water volume of 1.37 billion km^3 covering 361 million km^2, and rivers cover an area of 773,000 km^2, illustrating the vast scale of the task. A meta-analysis showed that none of the PRTs had been evaluated for removal efficiency.[4]

Ethical, political, and economic aspects

Equity and justice

Less-affluent municipalities and communities ultimately bear the brunt of plastics removal, while often lacking adequate policy frameworks, financial resources, and the latest independent scientific consensus on the environmental impacts of PRTs. These lacunae facilitate the externalization of the cost of plastics and could explain why almost no EIAs are conducted on PRTs. This issue could lead to further exploitation by actors selling plastics offsets in a potential new market facilitated by the Plastics Treaty.

Verifiability and leakages

Removing plastics does not eliminate the problem; it simply shifts it from one place to another. Collected plastics can rarely be reused or recycled. At least 13,000 chemicals are used to make plastics, a quarter of which are classified as hazardous.[14] Plastics also attract persistent organic pollutants from water and undergo weathering,[1] which diversifies their composition and reduces their suitability as feedstocks for waste management technologies and toxic-free products.[14] This means that even where plastics can be removed from water before fragmentation, most are destined for landfills or thermal treatment plants (Figure 1), increasing greenhouse gas emissions, air, soil, and water pollution, using up land, and concentrating hazards in receiving communities. An independent evaluation of the impacts is needed to support the claim that PRTs offer a safe, sustainable, and significant "solution" to the plastics crisis.

Greenwashing

PRTs could become a tool used by plastics producers to justify continued production growth with externalized costs. PRTs enjoy a high profile and visual appeal in the media. There is a significant risk that plastics manufacturers finance PRTs to offset their production under the guise of extended producer responsibility or plastics credit schemes. This will further shift responsibility for the externalized costs of plastics production away from producers to the rest of society.

Diversion from better solutions

Mainstreaming the focus on PRT innovation diverts resources away from effective prevention, does nothing to reduce escalating global plastics production, and can lull consumers into a false sense of security. Importantly, ambitious upstream action targeting plastics production costs society less than any other action, including waste collection or business as usual (18% lower cost[3]). Effective affordable options are crucial for low-GDP states.

Recommendations

In certain situations, PRTs may be warranted as part of larger restoration efforts, to improve public health, waterway hydrology, and to remediate heavily polluted land. Ideally, these will be interim measures while plastic production, as the source of pollution, is significantly phased down. We recognize that existing accumulated waste needs to be addressed and managed in the most sustainable ways possible. Focus should however be on handling the vast amounts of existing waste at landfills and unofficial dumpsites preventing environmental contamination. Further, in light of the triple planetary crisis (climate change, biodiversity loss, and pollution), claims that PRTs are a safe and sustainable solution to the global plastics crisis require independent scientific evaluation based on rigorous and globally standardized EIA criteria,[12] including climate costs, human health, rights, equity and justice, chemical emissions, organism mortality, and biodiversity loss. The costs of leaving plastic pollution in the environment should be transparently weighed against the cost of PRT efforts. These assessment criteria should be enshrined in the Plastics Treaty.

The most effective and cost-efficient way to prevent plastic pollution is to replace unsafe, unsustainable, and nonessential plastic chemicals, polymers, and products from the economy and to design safe, sustainable, and essential materials, products, and systems so that products retain their value.[14] Minimizing the amount and types of plastics produced globally while simplifying, detoxifying, and regulating the rest must be our main goal to move away from the most hazardous plastics and transform the plastics economy based on prevention, precautionary, and polluter-pays principles. The most effective measures will be grounded in global legally binding action,[15] underpinned by the zero-waste hierarchy,[8] to effectively eliminate plastic pollution throughout the full life cycle (Figure 1). Because of the uncertainties around PRT impacts, scalability, efficiency, and associated costs, they rank low on the zero-waste hierarchy as a temporary crutch to reduce existing plastics in pollution hotspots. However, to prevent undesirable outcomes, standardized, science-based assessment criteria must be independently established to evaluate the impact of PRTs on human health, the economy, and the environment.[12]

Successful historical precedents for the future Plastics Treaty can be found in multilateral environmental agreements (MEAs) focused on prevention rather than mitigation of chlorofluorocarbons, air pollution, and the release of oil residues from ships at sea. Member states would do well to look to those successful MEAs to guide negotiations toward an effective and comprehensive Plastics Treaty.

ACKNOWLEDGMENTS

M.B. is funded by the PoF IV research program "Changing Earth - Sustaining our Future" of the German Helmholtz Association. H.P.H.A. is funded from the European Union's Horizon 2020 research and innovation program (No. 101036756). B.C.A. receives funding from Svenska Forskningsrådet Formas (No. 2021-00913). A.K.W. is funded by the Government of India's SERB-CRG research project on microplastics (File No. CRG/2021/004725, June 24, 2022). W.C. was funded in part by the McPike-Zima Charitable Foundation.

DECLARATION OF INTERESTS

B.C.A., P.V.G., T.F., S.G., and R.C.T. are unremunerated members of the steering committee of the Scientists' Coalition for an Effective Plastics Treaty (SCEPT), which is dedicated to communication of robust independent science to support evidence-based decision-making in the Plastics Treaty process and has a strong Conflict of Interest policy.

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