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A framework for inland cities to prevent marine debris: A case study from Durham, North Carolina

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Land-based sources of litter are increasingly recognized as significant contributors to marine debris, and rivers can carry debris to the coast from far-inland sources. In this paper, we demonstrate the important role inland cities can play in the marine debris crisis by reducing their own marine debris contributions. Given this role, we provide a framework for inland cities to prevent plastic pollution along with the lessons learned from introducing these strategies in Durham, North Carolina, a mid-sized, inland city that drains to the ocean through the Cape Fear and Neuse River watersheds. This framework guides city officials, resource managers, and community partners on how to characterize the plastic pollution problem in their city by collecting baseline data on plastic waste and litter. This framework also provides practical and equitable solutions for inland cities to address plastic pollution. We recommend that inland cities prioritize policy solutions that reduce waste at the source – to the extent that their state constitutions allow – and to also use authorities for stormwater controls to capture and remove debris as long as litter persists. Replicating this framework in other inland cities opens vast opportunities to manage and reduce marine debris from an often-overlooked source.

KEYWORDS

plastic, waste, pollution, policy, stormwater, marine debris, marine conservation

Introduction

Marine debris, most of which is plastic (Derraik, 2002), is one of the most pressing and challenging environmental threats of our time. Compared to other materials, single-use plastics (e.g., bags, bottles, straws, takeout containers, etc.) are slow to biodegrade in the environment, taking tens to thousands of years depending on the type of plastic and the environmental conditions (Chamas et al., 2020). Much of the plastic that enters the environment accumulates in the oceans, where it chokes and entangles wildlife

(Schuyler et al., 2014; Gall and Thompson, 2015), is a vector for chemical pollutants (Engler, 2012), and breaks up into microplastics and nanoplastics that contaminate the food chain when consumed by fish and other marine organisms (Wang et al., 2020a). The urgency to find solutions for marine plastic pollution is exacerbated by the projected rise in plastic waste generation: in a business-as-usual scenario, the global estimate of mismanaged plastic waste is expected to triple by 2060 (Lebreton and Andrady, 2019).

The United States' role in the marine debris crisis is significant. In 2016, the United States produced 42 million metric tons (MMT) of plastic waste, more than any other country in the world (Law et al., 2020). This ranking is not driven merely by the United States' relatively large population; the United States' per capita plastic waste generation, at 130 kilograms/year, is the highest rate among top plastic waste-generating countries (Law et al., 2020). The wide availability of waste management infrastructure in the United States has not been enough to keep plastic waste from entering the environment. The United States still mismanages 1.13 to 2.24 MMT of plastic waste each year (Law et al., 2020). It is the second largest plastic waste exporter (Brooks et al., 2018) and the third largest contributor of plastic to the coastal environment (Law et al., 2020).

For the United States to seriously curb its contribution to marine pollution, a comprehensive national strategy is needed. Federal statutes enacted to date fall short. The Marine Plastic Pollution Research and Control Act of 1987 prohibits vessels from discharging plastics into jurisdictional waters of the United States but does nothing to address on-land sources of debris. In 2020, Congress took another small step by passing the Save our Seas 2.0 Act, but this statute is inadequate to the task. Instead of reducing plastics at the source, the Act requires research on plastic reuse in consumer products, microfiber pollution, circular polymers, and derelict fishing gear sources and recycling; authorizes funding for domestic clean-up and waste management infrastructure; and encourages international engagement. The Break Free from Plastic Pollution Act of 2021 is the strongest and most aggressive bill introduced to Congress to date to address plastic pollution. Among many directives, the bill places responsibility on producers to manage products after consumer use, phases out single-use products, standardizes labelling for recyclable and compostable products, and limits plastic waste exports to other countries. Whether Congress will pass the Break Free from Plastic Pollution Act into law, however, remains uncertain.

Absent a national plastic reduction strategy, the implementation of reduction policies in the United States has been, and must continue to be, driven by state and local governments. In this paper, we examine how scientific understanding of the geographic sources of marine debris has evolved and argue that local policies must evolve in response. Marine debris is commonly thought to be a coastal problem, and local policies to reduce single-use plastics (i.e., straws, takeout containers, and bags) have been concentrated in coastal areas (The Surfrider Foundation, 2021). However, inland cities have a pivotal role to play in combatting the marine debris crisis by reducing their own contributions of debris to inland waters. Recognizing this critical function, we provide a framework for inland cities to prevent plastic pollution – through effective "upstream" and "downstream" solutions – along with the lessons learned from introducing these strategies in Durham, North Carolina.

Geographic sources of marine debris: (In)land and sea

Riverine plastics

Scientists' understanding of the sources of marine debris has changed since plastic contamination in the ocean was first discovered in the 1970s (Carpenter et al., 1972; Carpenter and Smith, 1972). In early studies, marine plastics were attributed to ocean-based sources, such as shipping vessels (Scott, 1972; Colton et al., 1974; Horsman, 1982), or to discrete wastewater discharges from plastics manufacturing plants (Colton et al., 1974; Kartar et al., 1976). Starting in the late 1980s, the scientific consensus shifted to recognize that most marine debris originates from diffuse, on-land sources, primarily urban runoff and stormwater discharges (Bean, 1987; Gregory, 1991; Faris and Hart, 1994; Nollkaemper, 1994; UNESCO, 1994). Accordingly, focus shifted from ocean-based sources to quantifying and addressing waste mismanagement in coastal communities (Ribic et al., 2010; Jambeck et al., 2015). Jambeck et al. (2015) estimated 8.7 MMT of plastic debris enter the oceans every year from communities within 50 kilometers of the coast.

In the last decade, studies have documented that marine debris can originate farther inland than previous estimates acknowledged, uncovering the role that inland communities play in contributing to, and thus preventing, marine debris. Rivers carry debris to the ocean from inland areas (Lechner et al., 2014; Morritt et al., 2014; Rech et al., 2014; van Emmerik et al., 2019; Duncan et al., 2020), and rivers draining relatively more urbanized watersheds contain higher concentrations of micro- and macro-plastics (Browne et al., 2011; Yonkos et al., 2014; Baldwin et al., 2016; Birch et al., 2020). This is not only because urban areas generate more plastic pollution, but also because plastics are more mobile in urbanized watersheds due to the effectiveness of impervious surfaces and stormwater conveyances at transporting littered plastics (Baldwin et al., 2016).

Scientists are just beginning to understand the magnitude of marine debris contributions from inland areas, but they are finding the contributions are significant. Lebreton et al. (2017) estimated that 1.15 to 2.41 MMT of plastic waste enter the ocean every year from inland areas (>50 km upstream) *via* river transport. Another study on riverine plastic exports generated similar results, estimating that 0.47 to 2.75 MMT of plastic are deposited in the ocean from rivers every year (Schmidt et al., 2017).

Mismanaged plastic exports

River discharges are not the only way that inland cities contribute to marine debris. Plastic waste exports can also become marine debris when mismanaged by the importing country. Beginning in the 1990s, municipal recycling programs profited from exporting plastic waste, as it became costly to process and recycle the low-quality, mixed waste in the United States. From 1988 to 2016, the United States exported 26.7 MMT of plastic waste (Brooks et al., 2018). In 2016 alone, 1.99 MMT of plastic collected by United States' recycling programs were exported (Law et al., 2020). Most of this exported plastic went to countries that mismanage at least 20% of their waste, primarily China. However, since China's National Sword policy went into effect in 2018, banning most plastic waste imports, the recycling market has been severely disrupted. Some municipal recycling programs in the United States shuttered; others redirected their waste exports to countries in Southeast Asia that also have high rates of waste mismanagement, including Thailand, Malaysia, and Vietnam (Jambeck et al., 2015; Law et al., 2020; Wang et al., 2020b). Thus, it is reasonable to assume that a portion of the United States' plastic exports end up as marine debris.

A framework for inland cities to reduce marine debris

A comprehensive solution to the marine debris crisis requires inland cities to reduce their contributions of plastic debris to the environment. However, developing recommendations for local governments presents unique challenges compared to developing a national strategy. Local governments operate under different legal regimes since their powers are granted by the state, and limits on local government authority narrow the policy toolkit. Local governments also have varying access to waste management infrastructure. For example, only 59.5% of the United States' population has access to curbside recycling services (Sustainable Packaging Coalition, 2020-2021). Access to municipal composting to process compostable plastics is rare. Only 7% of the 1,000 largest United States' cities have a municipal curbside composting program that accepts both food waste and compostable packaging (GreenBlue, 2020).

Despite these challenges, we have identified a set of unifying principles for local action and policy. This framework encourages inland cities to 1) collect data prior to policy development, 2) develop policies that reduce waste at the source, and 3) use stormwater controls to capture mismanaged waste (Figure 1). Since 2016, the authors of this perspective have been working with the City of Durham, North Carolina to implement this framework. Durham is a mid-sized (population: 283,506), inland city located 125 miles from the

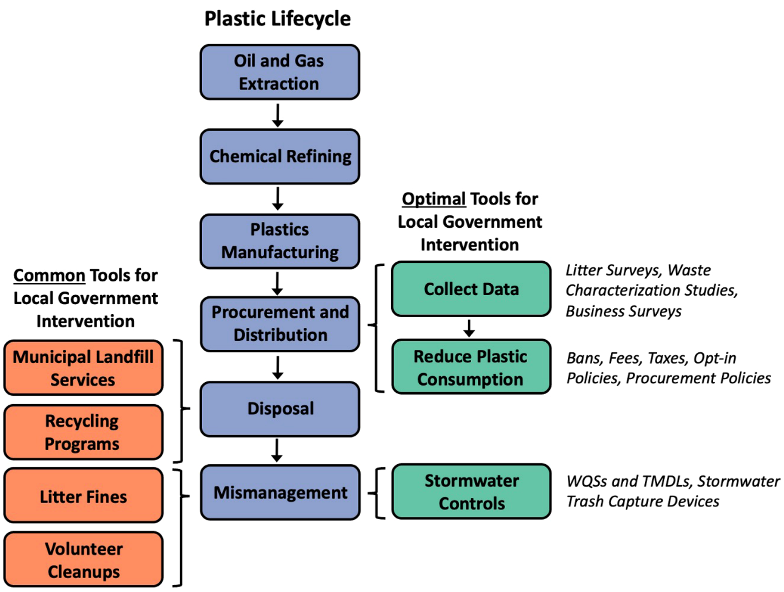

FIGURE 1
The plastics lifecycle shown with the common and optimal policy tools to reduce plastic pollution at the local level.

coast. Durham drains to the Atlantic Ocean through the Neuse River Basin (HUC 030202) and the Cape Fear River Basin (HUC 030300). While our policy work remains in progress as of this writing, our framework and lessons learned are valuable to city officials, resource managers, and community partners in other inland cities.

Collect data to inform policies

One benefit of addressing marine debris at the local level is that policies can be tailored to the needs of an individual community. However, for a policy to be responsive to those needs, data-collection must be done upfront to identify frequently mismanaged plastics and stakeholder concerns. In Durham, we conducted litter surveys, reviewed waste characterization studies, and surveyed local businesses prior to shaping a proposal to require businesses to charge a fee for single-use bags, no matter their material, at the point-of-sale. This proposal was informed by the prevalence of plastic bags and films in Durham's waste and litter streams and widespread support from local businesses for a bag-fee policy.

Litter surveys and waste characterization studies reveal the types and quantities of plastic items that dominate the waste stream and frequently escape to the environment. This information can inform which plastic items a policy should target and provide baseline data for measuring the policy's effectiveness following implementation. In Durham, for example, we documented the number and types of litter in 13 stretches of urban stream, two parks, and along roads of one neighborhood. We categorized over 7,000 pieces of litter and found that plastic film was the most common litter type (39% of litter by number). Municipalities can also conduct a waste characterization study, which identifies the types and amounts of trash the community generates to inform reduction policies and goals. According to Durham's 2015 Waste Characterization Study, ~7% of landfilled waste by weight is non-rigid plastic film, the largest category among plastic waste types.

While litter surveys and waste characterization studies identify the plastic item(s) a policy should target, surveying businesses informs what interventions would be practical for businesses to implement. Prior to developing our proposal, we surveyed local businesses (supermarkets, restaurants, convenience stores, retailers, etc.) on their attitudes about plastic reduction strategies and found that 85% of the 60 responding business supported or were neutral towards a plastic bag fee (Don't Waste Durham, 2021). We also found that businesses were concerned with the cost of alternatives, confirming the need for a policy that would not require businesses to purchase expensive alternatives. Distributing surveys in person provided the opportunity to engage with business owners and managers, who sometimes shared perspectives that went beyond the survey questions. These conversations highlighted the need for city-driven education and outreach to accompany any policy, and for the city to provide free reusable alternatives to low-wealth community members.

Reduce waste at the source

For inland cities, the problems with plastic consumption and pollution extend beyond the downstream effects of marine debris. Limited landfill space, the siting of landfills in low-wealth communities of color (Norton et al., 2007), the costs to clean up litter (Stickel et al., 2013), microplastics in drinking water (Pivokonsky et al., 2018), and contamination of the municipal recycling stream may all be reasons why an inland city government would act. Indeed, all local governments in the United States implement some laws and programs to reduce mismanaged plastics. For example, all 50 states have some form of litter law to discourage litter through fines and penalties (NCSL, 2022). Many local governments provide curbside garbage collection and remove litter along roadways through street sweeping and storm drain cleaning. Local governments also partner with non-profits, such as Keep America Beautiful affiliates and Riverkeepers, to support volunteer cleanups. However, these common interventions manage plastics only at the end-of-life. To maximize the co-benefits of a marine debris policy, we recommend that inland cities shift their policies and programs to intervene as early in the plastic lifecycle as possible by prioritizing reduction at the source (Figure 1). Source reductions should prioritize items that dominate the litter and waste streams.

Reducing plastic use and waste generation has shown to reduce mismanaged plastic waste in models (Jambeck et al., 2015; Lebreton and Andrady, 2019) and in practice. Bans, fees, and taxes have been successful in reducing single-use plastic consumption and mismanagement. Following taxes on single-use bags in Chicago, Illinois (Homonoff et al., 2018) and Montgomery County, Maryland (Homonoff, 2018), fewer customers used single-use bags, more customers used reusable bags or no bag at all, and customers who still used disposable bags used fewer. Diana et al. (2022) found that bans and fees reduced plastic bag consumption by an average of 66% across 27 jurisdictions all over the world. These reductions have translated into less bag waste and fewer bags littered in the environment (Schnurr et al., 2018).

Plastic bag reduction policies are one of the most common local policy tools (Wagner, 2017), likely due to the prevalence of bags and the many problems specific to mismanaged bags. Littered plastic bags are eye-catching and mobile, and easily snag on trees and storm drains. Plastic bags also jam equipment at sorting facilities for recyclables and can be costly to clear from machinery. In Durham, our immediate proposal targets single-use bags only. However, a comprehensive reduction strategy would target all plastics that commonly end up as marine debris, such as utensils, straws, beverage bottles, and take-out containers

(Ocean Conservancy, 2021). The reduction policy toolkit available to local governments is provided in Table 1. Importantly, some municipalities will be limited in what they can do by their state constitutions. In other states, local governments are preempted from regulating plastics (Bell and Todoran, 2022). In such cases, local governments can encourage businesses to voluntarily reduce plastics by recognizing their efforts through a certification or other market-based incentive program. They may also prohibit using municipal funds to buy single-use plastics.

Plastic reduction strategies should be designed to minimize burdens on disadvantaged community members. Low-income households are disproportionately affected by fees and taxes because they spend a larger proportion of their income on food and basic expenses (Johnson, 1999). One way to make fee-policies more equitable is to exempt low-income residents, defined by those who participate in supplemental assistance programs, such as SNAP, WIC, or Medicaid. Another strategy is to distribute and recirculate free reusable items. Local Durham nonprofit and our client, Don't Waste Durham, runs two programs, Boomerang Bags and GreenToGo, that provide and recirculate reusable bags and takeout containers through select retailers. In Durham, we proposed using the revenue from a bag fee policy to support and expand this type of reuse infrastructure to provide low-wealth residents with easily accessible, free alternatives to single-use plastics.

Use stormwater controls to capture leaks

Even with a comprehensive reduction strategy, plastics will escape to the environment. While common strategies implemented by local governments target plastics at the end of life, these strategies largely ignore stormwater- and river-transported plastics, major inland sources of marine debris. However, all local governments have the authority to manage these sources under the federal Clean Water Act. Under this authority, which requires urban areas to obtain pollution control permits for discharges from their Municipal Separate Storm Sewer Systems (MS4), local governments can require trash capture devices such as curb inlet covers, catch basin screens, and in-stream booms to reduce the amount of trash discharged *via* stormwater. In addition, governments can require businesses whose waste is collected by the MS4 to improve their on-site solid waste management practices (Sechley and Nowlin, 2017).

Trash capture devices, especially those installed at the stormwater inlet, can contribute to flooding during heavy storms if not properly maintained. As such, cities must invest in the necessary infrastructure (staff capacity, vacuum trucks, etc.) to ensure devices are regularly cleared. Since our initial 2018 proposal to the City of Durham to amend Durham's Stormwater Management Program Plan to address litter, the City of Durham has begun a pilot study to determine the effectiveness of catch basin collection devices. The city has partnered with a local non-profit, the Ellerbe Creek Watershed Association, to monitor and clean the devices. This type of partnership can lessen the time burden to municipal stormwater offices and may be vitally important to ensure that trash capture devices are well-maintained. In such an arrangement, non-profits will incur additional expenses and should be compensated. In sum, the costs and efforts associated with waste removal underscore the importance of reduction at the source.

TABLE 1 Policy options available to local governments aimed at reducing plastics at the source.

Policy tool	Commonly targeted plastics	Description	Considerations
Bans	Bags, Straws, Stirrers, Polystyrene Foodware	Prohibits retailers from providing single-use item(s).	As has been shown for single-use bags (Taylor and Villas-Boas, 2016; Taylor, 2019; Macintosh et al., 2020), increased consumption of other single-use items can occur unless there is a ban or fee on the alternatives.
Fees and Taxes	Bags, Bottled Beverages, Takeout Containers	Requires retailers to charge a small fee (\$0.05-\$0.25) for the item(s). Fees may be retained by the retailer, by the government, or shared.	The design of the charge is important for determining its classification as a fee or a tax. For some municipalities, imposing a tax is unlawful without explicit state government approval. If the charge is remitted to the city, it can be classified as a fee if designated to a fund for related purposes, such as waste management, litter clean-ups, or providing reusable items to residents.
Opt-in or "Available Only Upon Request" Policies	Takeout Utensils, Straws, Stirrers, Condiment Packets	Retailer provides item(s) only if a customer specifically requests the item(s).	Opt-in policies reduce unnecessary plastic waste while saving businesses money. They require additional employee training and consumer education to implement.
Procurement Policies	Potentially All Single-use Plastics, including Bags, Foodware, Bottled Beverages, etc.	Prohibits the use of government funds to purchase single-use item(s).	Significant consideration should be given to replacement items to ensure that one environmental harm is not being replaced with another. If replacing plastic with compostable or disposable alternatives, the city must have the appropriate composting or recycling infrastructure to properly manage the waste.

Conclusions

Inland cities contribute significantly to marine debris through river discharges and mismanaged plastic exports. Until an effective national plastic reduction strategy is implemented, local level action is an essential component of a response to the marine debris crisis. The framework presented in this article encourages inland city officials, resource managers, and community partners to 1) collect data prior to policy development, 2) develop policies that reduce waste at the source, and 3) use stormwater controls to capture mismanaged waste. Stakeholder involvement and equity must be a central focus of any plastic reduction strategy to lessen the burden on and respond to the needs of those most affected, especially local businesses and low-wealth residents. Implementing this framework in inland cities across the United States will reduce the problems with marine debris downstream and the problems with plastic waste at home, such as contaminated drinking water, contaminated recycling, landfill space, and litter.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

NL wrote the first draft of the manuscript. MN revised the manuscript several times. Both authors contributed to the conception of the framework and the supporting research. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The Duke Environmental Law and Policy Clinic is an academic, experiential-learning program offered by Duke Law School and open to law students as well as professional degree students from Duke's Nicholas School of the Environment. The Clinic is funded by the Law School. The Clinic teaches the practice of environmental law and policy through formal representation of non-profit clients that seek assistance addressing environmental problems in their respective communities. Under supervision of Clinic faculty, students interact directly with these clients, conduct legal, scientific and policy research on their behalf, provide guidance, and represent their interests in legal, regulatory, and policy settings as appropriate. All services are provided on a pro bono basis. Our article arises from work we and our students have conducted on behalf of Clinic client Don't Waste Durham. Our perspective and distillation of best practices is based on this experience.

Publisher's note

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