Marine Plastics

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Briefing Document: Land-Based Plastic Waste as a Primary Source of Marine Pollution

Sources:

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Summary

An estimated 4.8 to 12.7 million metric tons (MT) of plastic waste entered the world's oceans from land-based sources in 2010 alone, a figure one to three orders of magnitude greater than the reported mass of all floating plastic debris. This significant influx is primarily driven by the size of coastal populations and, most critically, the quality of municipal solid waste management systems. Middle-income countries, which are experiencing rapid economic growth that outpaces the development of waste management infrastructure, are the largest contributors; 16 of the top 20 contributing nations fall into this category, accounting for 83% of all mismanaged plastic waste.

Rivers serve as a primary conduit for this waste, transporting an estimated 0.41 to 4 million MT of plastic to the sea annually. The contribution is highly concentrated, with the top 10 river systems—eight of which are in Asia—transporting between 88% and 95% of the total global riverine plastic load. This is due to a nonlinear relationship where large, population-rich catchments deliver a disproportionately high fraction of their mismanaged plastic waste.

Projections indicate that without significant improvements in waste management, the cumulative quantity of plastic waste available to enter the marine environment will increase by an order of magnitude by 2025. Mitigation efforts focused on substantial infrastructure investment in the top contributing countries and river basins offer the most effective path to drastically reduce plastic pollution. A 50% reduction of mismanaged waste in the top 20 countries could decrease the total input by 41% by 2025, while a 50% load reduction in the top 10 rivers could cut the total river-based contribution by 45%.

Quantifying the Global Influx of Land-Based Plastic

Scientific analysis provides a foundational, order-of-magnitude estimate of the plastic waste entering the marine environment from terrestrial sources, identifying the primary drivers and geographic hotspots of pollution.

The 2010 Global Estimate

A 2015 study by Jambeck et al. provided the first rigorous global estimate of land-based plastic waste entering the ocean. The analysis, which linked worldwide data on solid waste, population density, and economic status for 192 coastal countries, produced the following key figures for the year 2010:

- Total Plastic Waste Generated: 275 million metric tons (MT) were generated by the 192 countries, which accounted for 93% of the global population. This figure roughly tracks global plastic resin production (270 million MT in 2010).
- Coastal Plastic Waste: Populations living within 50 km of a coast generated an estimated 99.5 million MT of plastic waste.
- Mismanaged Waste: Of the coastal plastic waste, 31.9 million MT were classified as "mismanaged." This is defined as material that is either littered or inadequately disposed of in systems like open, uncontrolled dumps where it is not fully contained.
- Ocean Input: From the mismanaged coastal waste, an estimated 4.8 to 12.7 million MT entered the ocean. This wide range reflects uncertainty in the conversion rates of mismanaged waste to marine debris.

This estimate of plastic entering the ocean is one to three orders of magnitude greater than the reported mass of plastic observed floating in ocean gyres, pointing to a significant knowledge gap regarding the ultimate fate and location of marine plastic.

Geographic Distribution and Key Contributors

The mass of mismanaged plastic waste is not evenly distributed globally. It is largely determined by population size and the percentage of waste that is mismanaged. The analysis identified the top 20 countries ranked by the mass of mismanaged plastic waste, which collectively account for 83% of the total.

- Dominance of Middle-Income Countries: Sixteen of the top 20 contributing countries are classified as middle-income (Upper Middle, Lower Middle), where rapid economic growth and increasing plastic consumption are often not matched by corresponding development in waste management infrastructure. These nations typically have high percentages of mismanaged waste (e.g., China 76%, Indonesia 83%, Vietnam 88%).
- Role of High-Income Countries: High-income countries can also be significant sources due to high per capita waste generation, even with low rates of mismanagement. The United States, for example, ranks 20th. Despite having only a 2% mismanaged waste fraction, its large coastal population and high waste generation rate (2.58 kg per person per day) result in a substantial mass of mismanaged plastic waste (0.28 million MT/year).

The following table details the estimates for the top 20 countries in 2010.

Rank	Country	Economic Classification	Coastal Pop. (millions)	Waste Gen. Rate (kg/ppd)	% I
1	China	UMI	262.9	1.10	
2	Indonesia	LMI	187.2	0.52	
3	Philippines	LMI	83.4	0.50	
4	Vietnam	LMI	55.9	0.79	
5	Sri Lanka	LMI	14.6	5.10	
6	Thailand	UMI	26.0	1.20	
7	Egypt	LMI	21.8	1.37	
8	Malaysia	UMI	22.9	1.52	
9	Nigeria	LMI	27.5	0.79	
10	Bangladesh	LI	70.9	0.43	
11	South Africa	UMI	12.9	2.00	
12	India	LMI	187.5	0.34	
13	Algeria	UMI	16.6	1.20	
14	Turkey	UMI	34.0	1.77	
15	Pakistan	LMI	14.6	0.79	
16	Brazil	UMI	74.7	1.03	
17	Burma	LI	19.0	0.44	
19	Morocco	LMI	17.3	1.46	
19	North Korea	LI	17.3	0.60	
20	United States	HIC	112.9	2.58	

Note: Coastal European Union countries (23 total), if considered collectively, would rank 18th.
Source: Jambeck et al., Science (2015)

Rivers as the Primary Pathway to the Sea

While initial estimates focused on waste generated in coastal zones, further research has established that rivers are a major transport pathway, connecting vast inland populations and their waste to the marine environment.

The Role and Scale of Riverine Transport

Analysis of a global dataset of plastic debris in river water columns confirms that rivers act as a major conveyor for plastics of all sizes.

- Global River Input Estimate: Based on observed plastic loads, rivers are estimated to transport between 0.41 and 4 million MT of plastic into the sea annually. The wide range of this estimate is due to high uncertainty from sparse and heterogeneous data.
- Nonlinear Relationship: The amount of plastic transported by a river is positively but nonlinearly related to the amount of mismanaged plastic waste (MMPW) generated in its catchment. This means that large rivers with population-rich catchments deliver a disproportionately higher fraction of their available MMPW into the sea. This relationship is demonstrated by a log-log linear regression slope greater than 1.

Disproportionate Contribution from Major Rivers

A critical finding is the highly concentrated nature of riverine plastic emissions. The disproportional transport dynamics mean that a small number of rivers are responsible for the vast majority of the global plastic load.

- Top 10 Rivers: The 10 top-ranked rivers are calculated to transport 88% to 95% of the total global plastic load that enters the sea via rivers.
- Geographic Concentration: Eight of these top ten highest-load catchments are located in Asia, reflecting the convergence of large populations and high rates of MMPW generation in these regions.

This concentration suggests that plastic accumulation is a significant issue within river systems themselves, with debris being retained on river banks and in bed sediments before eventual transport to the ocean.

Future Projections and Mitigation Strategies

Under a business-as-usual scenario, the problem of marine plastic pollution is projected to worsen significantly. However, the analytical frameworks used to quantify the problem also allow for the evaluation of potential mitigation strategies.

Business-as-Usual Projections for 2025

Assuming no improvements in waste management infrastructure, the cumulative quantity of plastic waste available to enter the marine environment from land is predicted to increase by an order of magnitude by 2025. The geographic distribution of mismanaged waste is not expected to change substantially, but the disparity between developing and industrialized countries will grow. For example, mismanaged plastic waste in the United States is projected to increase by 22%, whereas in the top five contributing countries, it is expected to more than double.

Evaluating Mitigation Scenarios

The concentration of plastic sources in specific countries and river basins presents an opportunity for highly targeted and effective interventions.

- Improving Waste Management: This is identified as a paramount strategy. A 50% improvement in waste management (i.e., a 50% reduction in mismanaged waste) in the top 20 countries would decrease the total mass of mismanaged plastic waste by 41% by 2025.
- Targeting Key Rivers: Given their outsized role, focusing on the highest-polluting rivers is highly efficient. Reducing the plastic loads by 50% in the 10 top-ranked rivers would reduce the total global river-based load to the sea by 45%.
- Reducing Waste Generation: An alternative strategy involves reducing waste generation and plastic use, primarily targeting higher-income countries. Capping per capita waste generation and the percentage of plastic in the waste stream in the 91 countries that exceed the 2010 average would achieve a 26% decrease by 2025.
- Combined Strategy: A 77% reduction in annual plastic input to the ocean could be realized by 2025 through a combined strategy of achieving 0% mismanaged waste in the 10 top-ranked countries and capping plastic waste generation globally.

Broader Context and Knowledge Gaps

The influx of plastic into the ocean is a direct consequence of the material's properties, its production trajectory, and its end-of-life management.

The Rise of Plastic Production and Waste

The problem is rooted in the exponential growth of plastics production, which has increased from less than 50 million MT per year in the 1970s to 311 million MT in 2014.

- Packaging Dominance: The largest market demand for plastics is for packaging materials (35% in the U.S.), which are designed for short-term use and immediate disposal.
- Low Recovery Rates: Despite the recyclability of many plastics, recovery rates remain low. In 2012, only an estimated 8.8% of postconsumer plastics were recovered for recycling in the United States; in Europe, the rate was 30% in 2014.
- Persistence: Plastics are synthetic organic polymers that are resistant to biodegradation, making them a persistent form of litter in the marine environment.

Environmental Fragmentation

Once in the marine environment, particularly when exposed to sunlight at the sea surface or on coastlines, plastics undergo weathering. Exposure to UV radiation initiates photo-oxidative degradation, which weakens the material and leads to fracturing and fragmentation into progressively smaller particles, including microplastics (<5 mm).

Key Uncertainties and Research Needs

While the scale of the problem is becoming clearer, significant knowledge gaps remain:

- Data Scarcity and Standardization: There is a lack of standardized methodologies for sampling and analyzing plastic debris across different marine reservoirs (sea surface, water column, seafloor, etc.), which hinders global-scale assessments.
- Refining Input Estimates: Estimates of plastic inputs from land and rivers are based on models that require more empirical data for validation, including direct measurements of waste transport by rivers, wind, and tides.
- Fate of Marine Plastics: The discrepancy between the high estimated inputs and lower observed quantities of floating plastic (the "missing plastic" problem) highlights the need to better understand the fragmentation, transport, and ultimate sinks (e.g., seafloor, biota, sediments) of plastic in the marine environment.