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Tracking the Path of Ocean Plastic Pollution in Southeast Asia:

Insights from modelling and monitoring the circulation of marine debris in Indonesia[1]

- Use numerical models to track the trajectories of plastic waste to identify the main seasons and places of accumulation. This will facilitate the coordination of decontamination actions by local communities or other relevant actors.
- In the case of large plastic accumulations, analyze the models backward to trace the plastic waste back to its origins along rivers and coastlines. This will inform targeted prevention actions at the source of the pollution.
- Identify the most exposed and fragile ecosystems by improving interdisciplinary knowledge on the dynamics of plastic pollution and their interactions with environments.

Southeast Asian countries face a significant plastic pollution challenge. Indonesia, for example, was generating in 2020 a staggering 6.8 million tons of plastic waste annually, with an estimated discharge of 620,000 tons of plastic into the marine environment each year (Indonesia NPAP analysis, 2020). Six amongst the ten largest contributors to marine plastic debris are located in Southeast Asia[2]. Together, these six countries account for more than half of the world's ocean plastic pollution. The consequences of this plastic pollution are severe, impacting the region's rich biodiversity, human health, and the livelihoods of tens of millions who rely on marine resources and tourism.

The combined effects of plastic pollution and climate change disproportionately impact vulnerable populations, increasing exposure to extreme weather events, disturbed environments and health risks associated with vector-borne diseases and heat exposure. Recognizing the interconnectedness of plastic pollution, biodiversity loss, and climate change, Southeast Asian authorities have taken a proactive stance.

Mirroring similar engagements in ASEAN (Association of Southeast Asian Nations) countries, the Indonesian government seriously tackles plastic pollution. It set a goal to reduce plastic marine debris by 70 % by 2025 (compared to 2018 levels) and outlined a National Action Plan with five key strategies to achieve this ambitious target:

[1] This brief is based on an AFD-funded study: Dobler *et al.* (2021).

[2] In order of annual plastic emission into the ocean (Meijer *et al.*, 2021): Philippines, Malaysia, Indonesia, Myanmar, Vietnam, Thailand.

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1. Promoting public awareness and encouraging responsible plastic use;
2. Addressing improper waste management practices to minimize plastic entering waterways;
3. Focusing on fishing gear and practices to minimize plastic entering the ocean;
4. Encouraging alternative materials and product designs to decrease virgin plastic usage;
5. Ensuring financial resources, effective regulations, and enforcement to support the action plan.

As of December 2023, Indonesia has reportedly achieved 41.68 % progress towards the 70 % reduction target (WRI, 2024).

This paper explores how advancements in modeling plastic particle trajectories can further contribute to the region's efforts in tackling plastic pollution and achieving such ambitious goals. It studies how plastic moves in Indonesian waters. Unlike other Southeast Asian countries where landfills dominate, rivers in Indonesia are the main source of plastic pollution in the oceans, and most of this plastic originates domestically. The study modeled plastic movement from 21 rivers and found that 60 % ended up on Indonesian beaches within 4 years (see the main stranding zones on Figure 1). Three rivers showed unique patterns: Deli River plastic traveled the farthest (5,442 km), while Jogja and Pelabuhan Ratu rivers stranded the fastest. Understanding these variations is crucial for better plastic waste management. Finally, 30 % of the plastic ended up in the Indian Ocean, highlighting the global reach of plastic pollution.

Figure 1 - Mapping of stranded particles along Indonesian coasts at the end of the 4-year stimulation. White stars indicate river mouths. The upper panel shows locations where more than 1,000 and more than 10,000 particles were stranded on Indonesian coasts. The lower panel focuses on islands of Java and Bali.

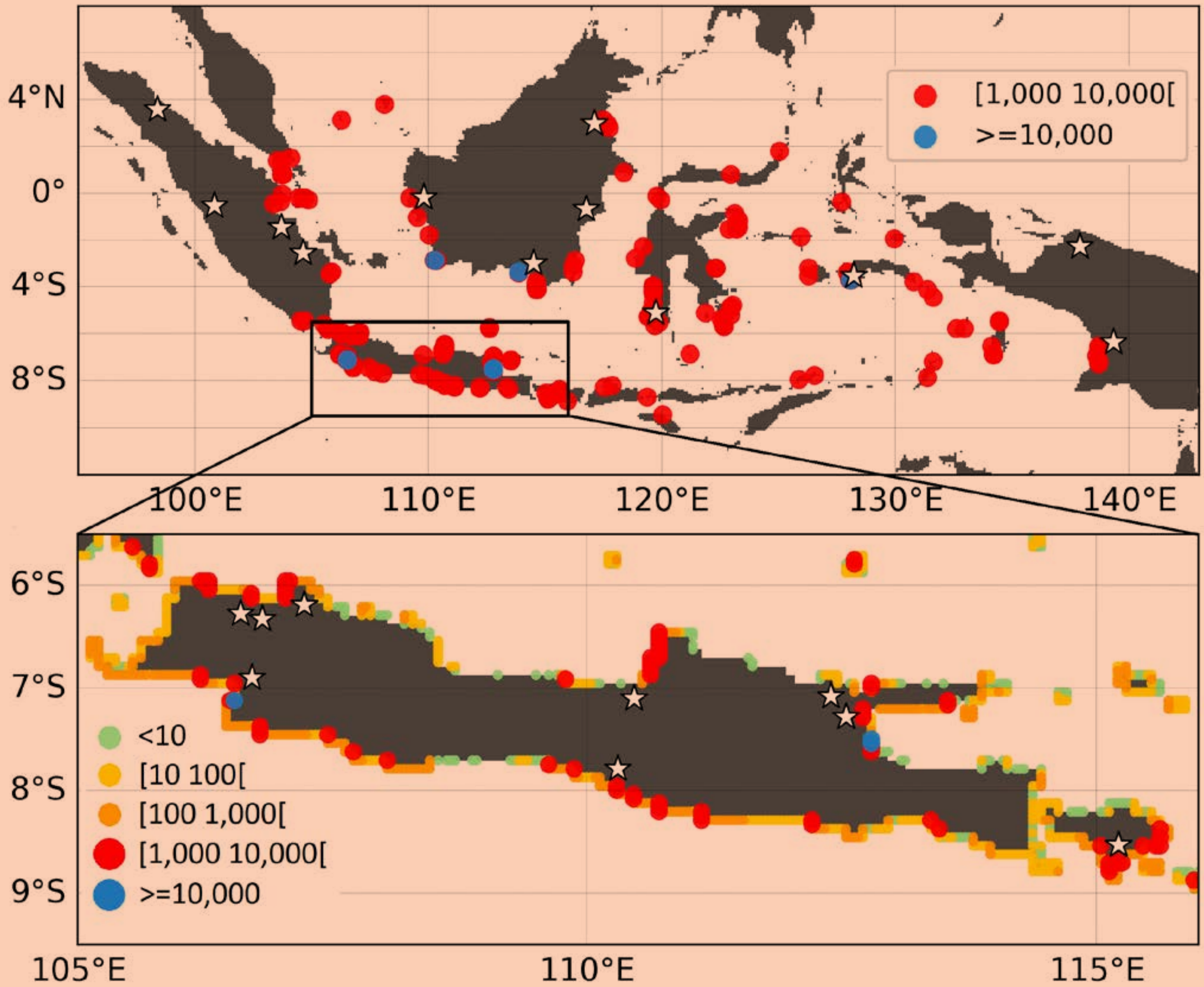
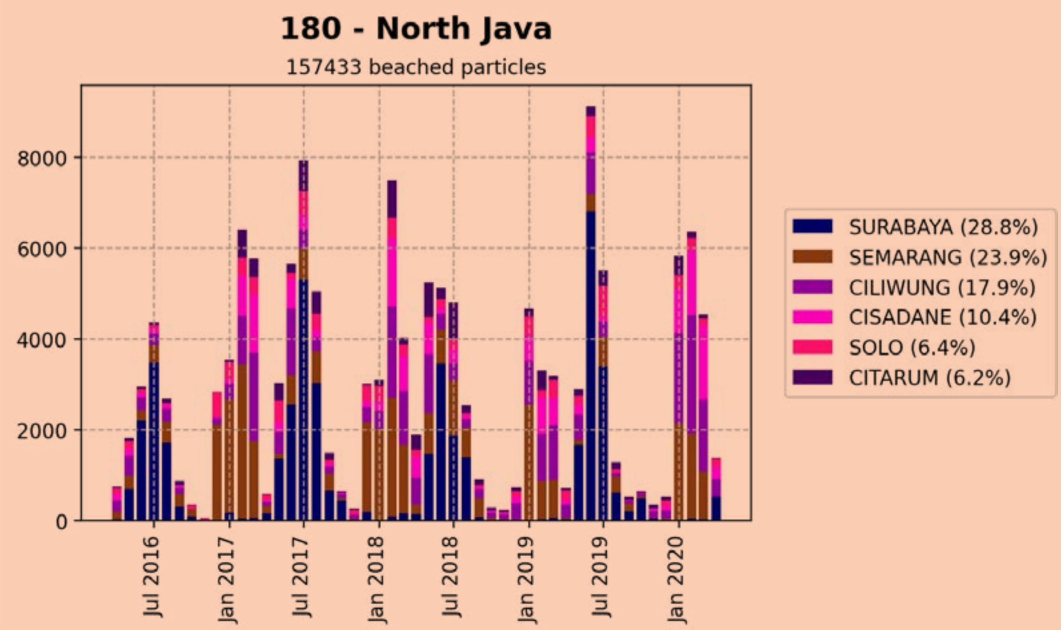


Figure 2 - Number of stranded plastic particles originating from the 6 main North Java rivers over a four-year period. The total number of stranded particles is 157,433, and the percentage contributed by each river is indicated in parenthesis. A clear seasonality is visible, depending on the river.



While large-scale currents and air-sea interactions govern plastic accumulation in the open ocean, coastal areas present a much more intricate and complex picture. Here, coastal processes and interactions with the seabed significantly influence plastic fate. The diverse habitats found along coastlines, including mangroves, seagrass meadows, and coral reefs, can act as either sinks or further accumulation zones for plastic debris. Understanding these complexities is crucial for future effective management strategies.

The detrimental effects of plastic pollution extend far beyond harming marine life. It disrupts entire ecosystems, altering both microbial and macrofaunal communities through a combination of mechanical and chemical means. Larger plastic pieces can become entangled in coastal habitats, causing physical damage and hindering their growth. On the other hand, microplastics and even smaller nanoplastics can potentially sink and be incorporated into the seafloor sediments, introducing a long-term threat to these biotopes.

The present study leverages the strengths of the Lagrangian method to provide a more comprehensive understanding of plastic particles' movement in the ocean. The Lagrangian approach provides the opportunity to track the entire history of a particle's trajectory, including interactions with different currents and the topography. Connectivity patterns between various areas can be analyzed and potential sources of plastic pollution identified. Furthermore, the model enables researchers to trace particles back to their origins, a crucial feature for targeted prevention strategies.

The study incorporates key factors, such as surface drift and tidal currents, to refine previous understanding of plastic dispersion patterns. The model's output aligns with a few but scarce real-world observations. Simulations identified a peak in stranded particles in the Selayar subzone during January and February, mirroring observations of local residents who witness bursts of plastic accumulation during this same period. This convergence between model predictions and real-observation data reinforces the reliability of the approach to inform future clean-up and prevention efforts.

Recommendation 1: Prevention at the Source

The ability to run plastic movement models backward, a key strength of the Lagrangian method, allows users to trace plastic debris back to its point of origin, and identify the specific rivers contributing the most to plastic pollution on various coastlines. In Indonesia, the data reveals a seasonal pattern with two peak periods coinciding with monsoons.

These peaks vary by region, one is centered around June-July and another is centered around January-February (see Fig. 2 for North Java).

While all rivers contribute some plastic, predictive models help identify major contributors. This detailed understanding empowers policymakers to develop targeted solutions. Interventions can focus on these specific rivers during peak pollution times, potentially involving improved waste management or infrastructure upgrades. The models can also guide the strategic placement of river-based traps to maximize plastic capture before it reaches the ocean. By focusing on source points, this approach has the potential to significantly reduce plastic entering the marine environment.

Recommendation 2: Optimizing Clean-up Efforts

Authorities can leverage predictive models of plastic movement to optimize clean-up efforts. By predicting debris accumulation hot spots, clean up campaigns could be more precisely planned and deployed on prioritized areas. This approach would not only maximize waste collection but also directly benefit fishermen by increasing their income potential through waste collection activities beyond traditional fishing seasons. This however requires that the developed tools are endorsed, used and maintained by national and local authorities.

Indonesia's "Love of the Sea Month" program, spearheaded by the Ministry of Marine Affairs and Fisheries, offers a valuable platform for tackling plastic pollution. The program's "Fishing for Litter" initiative incentivizes fishermen to collect marine debris in exchange for financial rewards. However, its current implementation is primarily confined to low fishing seasons, limiting its overall impact.

Imagine a scenario where fishermen are informed about areas with high concentrations of plastic debris, allowing them to dedicate their efforts to collecting this valuable "waste resource" during periods where fish stocks are low. This win-win situation improves environmental outcomes while strengthening the livelihoods of fishing communities.

Recommendation 3: Interdisciplinary Approach

The journey of marine plastic particles is complex, influenced by many factors, from the type of plastic and large-scale currents to interactions with microscopic marine organisms. Additionally, features like underwater topography, seabed type, and surrounding ecosystem play a role where plastic accumulates.

Effectively managing plastic pollution requires collaboration between various disciplines. Oceanographers, ecologists, waste management experts, and social scientists all have valuable insights to contribute. Engaging stakeholders at all levels, from policymakers to local communities, is also essential for developing successful solutions. Adopting ecosystem-based management approaches, as encouraged already by the National Action Plan in Indonesia, highlights the importance of considering the delicate balance of coastal environments and minimizing harm to marine life.

International research networks like PASSPORT-2C and PISCES Relay offer a powerful model for tackling plastic pollution. These collaborations foster knowledge exchange, methodology development, and the creation of solutions specifically designed for tropical ecosystems. By working together, researchers can develop the robust tools needed to address this complex challenge and ensure the health of our oceans.

Recommendation 4: Future Research Priorities

The fight against plastic pollution requires a deeper understanding of its long-term impacts on marine environments. Long-term experiments with organisms and dedicated observations across various habitats and ecosystems are essential, as well as long-term studies observing how plastic accumulates depending on the particle size, and how it alters ecosystems over extended periods. Research should move beyond the role of currents and delve into the influence of coastal features and local ecosystems.

The study identifies mangroves and coral reefs as potential plastic traps due to their complex structures. Further investigation is needed to understand the consequences of plastic accumulation on these ecosystems' health and the services they provide, considering the variety of plastic sizes and characteristics.

Another critical area for future research is "legacy pollution" – the vast amount of plastic already present in our oceans. Characterizing this existing plastic burden with a robust scientific approach is crucial to develop and evaluate methods for tackling it effectively.

Conclusion

In conclusion, a robust science-based and interdisciplinary approach is fundamental to effectively addressing the global challenge of marine plastic pollution. The study's advancements in modeling plastic particle trajectories offer a valuable tool for understanding the entire plastic pollution life cycle, from source points to accumulation zones in the oceanic and coastal environments. This study brings insights for developing targeted mitigation strategies and evidence-based policies. Regional and international collaboration including sharing research findings, can support the combat against plastic pollution and enable countries to pave the way for a sustainable future with healthier oceans free from plastic pollution, promoting policies in line with the Global Plastic Treaty under negotiation.

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