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Strategies and Practices for Marine Plastic Pollution Control: Challenges, Opportunities and Future Prospects

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Abstract:
Now human activities along coastline and over the ocean are now continuously growing and generating considerable impacts on the ocean ecosystem. And the marine plastic pollution remains a pressing global threat that harms the ecological balance, requiring urgent actions across technological, policy, and societal domains. This paper systematically focuses on the multifaceted challenges of marine plastic pollution, detecting its sources, types, distribution patterns, and governance mechanisms. According to the study, the varies sources of plastic wastes and the universal distribution of plastics—from surface to deep ocean—highlight the need for comprehensive governance that addresses both production sources and existing waste management. While international agreements like the UNEP's plastic pollution resolution provide the available regulations and effective implementation connections on strengthening the complement of regulations, expanding innovative technologies, and encouraging public participation. By analyzing current strategies, this research emphasizes the urgency of integrated approaches to address marine plastic pollution, providing a foundational framework for developing sustainable, globally coordinated solutions to protect marine biodiversity and human well-being.

Keywords: Marine plastic pollution; Sources; Governance; Technology; Policy

1. Introduction

Research has revealed that approximately 14 million tons of plastics are discharged into the ocean every year [1]. This numerous amount emphasizes that the plastic wastes has widely spread in the ocean and penetrated into the marine ecosystem [2]. Over recent years, the quantity of plastic entering marine environments has been on an upward trend. As the United Nations' International Resource Panel has announced that the amount of plastic leaking into the ocean is estimated to be nearly tripled in 2040, the urgent need of global governance turns to be ever emergent [3]. The difficulties of controlling and monitoring various diffuse pollution sources, such as industrial wastes, further complicate governance operation, and it will be a long-term striving [4]. Without more refined and coordinated strategies, marine plastic pollution is likely to intensify, especially when compounded by the effects of global climate change. Therefore, the situation of continuous growth of marine plastic pollution forces it to become a severe global ecological challenge to overcome.

The ecological impacts of marine plastic pollution are extensive and complex. When plastics enter oceans, circulating ocean currents trap them, directing some of these materials to the seabed, and the remnant wastes will remain on the ocean surface. Whatever the plastics are under or above the ocean, they all probably become the food of sea fish or seabirds, participating in the marine food chain. Additionally, the vast number of plastics have floated into the ocean, particularly the large-scale plastic aggregations like the Great Pacific Garbage Patch, physically alter the habitats of marine organisms. Moreover, plastic waste has spread to every corner of the ocean presently, and its proliferation is evident even in outlying regions like unpopulated islands [4]. In terms of biodiversity, marine organisms of all trophic levels are at risk. The demises of acoustic fish and birds occur due to accidentally eat the macroplastics, which are classified as molecules more than 5 mm in magnitude. Meanwhile, floating debris can be served as a carrier of the toxic elements. The molecules less than 5 mm in magnitude, which are defined as the microplastics, undergo accumulation along food chains [4], leading to physical damage to marine organisms, such as by internal abrasions and blockages [5]. Despite the environmental science having been substantially more advanced than previous, the comprehensive understanding of plastics' impacts on human health remains an area of active research. Especially, microplastics have been identified as potential vectors for human exposure through multiple pathways, with the food chain being a primary route [6]. Fish species inhabit the polluted waters, and the microplastics accumulate in their gastrointestinal tracts, with potential transfer to human consumers through the food chain.

Although the awareness of this global issue has grown a lot, the governance of marine plastic pollution is still facing challenges. Technologically, effective large-scale plastics removal from the ocean is complicated by the vastness of the affected areas and the diverse forms and sizes of plastic debris. Policy-wise, the fragmented international legal framework, being additional with the lack of binding agreements for reducing plastic production and consumption, obstructs the coordinated action among nations. Socially, changing consumer behavior and promoting sustainable waste management practices also face significant inertia, as plastic remains the essential material of choice for many people due to its convenience and low cost. In the face of various challenges and tests, the current governance of marine plastic waste is not yet significant and still requires further investigation and management.

Against this backdrop, this article proposes to state a synthetic review of current governing strategies of marine plastic pollution. By synthesizing the latest research on technological innovations, policy regulations, and social initiatives, the effectiveness and the flaws will be evaluated. These findings will deepen the understanding of the complexity of marine plastic wastes and provide critical insights for formulating more effective, sustainable strategies in the future.

2. The Sources and Hazards of Marine Plastic Waste

2.1 The Sources of Plastic Waste

2.1.1 Inland-based Sources

Inland activities are the primary sources of marine plastic pollution, contributing to approximately 80% of marine plastic inputs [7]. These sources are directly linked to human settlements, industries, and agricultural practices. Rivers are regarded as the most critical pathways for the transportation of microplastics from inland regions to the ocean [8]. The industrial activities, including manufacturing, packaging, and textile industries, generate plastic pellets, fibers, and residual waste, flowing into rivers from industrial wastewater and getting into the ocean. Agricultural plastics like mulch films (used to retain moisture in crops) and discarded fishing nets degrade into microplastics. Also, the pesticides and fertilizers applied to farmland can adsorb onto plastic particles, accelerating their transport via rainfall runoff into rivers and coastal zones.

2.1.2 Sea-based Sources

Sea-based sources originate directly from human maritime activities, including maritime industries, aquaculture, and entertainment activities. For instance, cruise ships, cargo vessels, and fishing boats can generate great amounts of plastic waste. Especially, illegal dumping of non-biodegradable waste overboard remains a significant issue, particularly in international waters [9]. Moreover, plastic cages, buoys, and feed bags used in fish farms are often improperly disposed of, contributing to coastal pollution, and the world's fishing fleet is considered to be the main offshore source in marine aquaculture [8]. Additionally,

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offshore industries such as oil and platforms, as well as marine construction sites, generate plastic waste.

2.1.3 Air-based Sources

Air-based transport of plastic particles is not as dominate as the previous two pathway, but it also plays a crucial role in transporting the plastic particle to the ocean, primarily involving microplastics and nanoplastics. Small plastic particles become airborne through wind erosion of landfills, industrial sites, or urban roads. These particles can travel long distances and settle into the ocean during rainfall or dry deposition. And combustion processes release tiny plastic-derived particles into the air, which eventually deposit in marine environments. A study in the North Atlantic found that atmospheric deposition contributes about 10–25% of microplastics in surface waters [10]. While minor compared to anthropogenic sources, volcanic eruptions and natural dust storms can carry soil particles that have contained plastic debris into the atmosphere, potentially transporting them over oceans.

2.2 The Types and Distribution of Marine Plastic Waste

2.2.1 Classification by Polymer Type

Firstly, thermoplastics are the most prevalent polymers in marine plastic waste. They are characterized by their ability to soften and ductile while heating, making them versatile for manufacturing. However, this durability also leads to long time persistence in the environment. Thermoplastics include polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyethylene terephthalate (PET); this type of marine plastic waste can absorb persistent organic pollutants (POPs) like PCBs and DDT, acting as vectors for toxic transfer to marine life [11].

Secondly, thermosetting plastics are kinds of the species of marine plastics, which are chemically cross-linked during production, making them rigid and non-recyclable through simple heating. They are less common in marine waste but also have raised hard challenges because of their durability. The sub-types of thermosetting plastics include epoxy resins and polyurethane (PU). Unlike thermoplastics, thermosets can not melt, so they accumulate as permanent solid debris in ecosystems. However, they may contain toxic components like flame retardants and heavy metals that will penetrate into the marine ecosystem [12].

The final type of marine plastics includes biobased and biodegradable plastics. These polymers are initially designed to reduce reliance on fossil fuels and enhance degradability, but their performance in marine environments is controversial. The typical types of biobased and biodegradable plastics are polylactic acid (PLA) and polyhydroxyalkanoates (PHAs). What is warning is that mismanagement of this type of marine plastic waste can lead to unintended pollution, as bioplastics may still persist as microplastics if not disposed of in controlled environments.

2.2.2 Global and Regional Distribution

The convergence zones like the Great Pacific Garbage Patch, North Atlantic Gyre, and Indian Ocean Gyre accumulate vast amounts of plastic due to the slow-moving currents. Emerging research highlights increasing plastic concentrations driven by westerly winds and Antarctic Circumpolar Current, with microplastics detected even in remote island ecosystems [13].

The high human activity areas are also considered to be a great region in plastic pollution. For example. The regions like the Mediterranean Sea and the Caribbean Sea, which contain 200,000 plastic pieces per squared kilometers, face severe pollution from urban runoff and tourism [14]. Moreover, major rivers like Yangtze and Mississippi transport land-based plastics to coastal areas. The Ganges-Brahmaputra delta alone contributes about 0.5 million tons of plastic to the Bay of Bengal annually [15].

Additionally, marine plastics can be detected in the deep-sea sediment. To be specific, microplastics have been detected at depths exceeding 10,000 meters in the Mariana Trench, with concentrations increasing with proximity to coastlines [16].

3 The Main Mechanisms for the Governance of Marine Plastic Wastes

2.3 Policy Governance Mechanisms

3.1.1 International Cooperation and Policy

Facing the global challenge of marine plastic wastes, which has increasingly captured public attention, the international policy and cooperation have become the essential and basic parts of the governance process. The United Nations Environment Programme (UNEP) is an environmental authority that leads the global development of environmental protection. In March 2022, United Nations published an programme, which focused on the plastic pollution management and also covers the concerns about the marine plastic pollution [18]. This programme is an international binding instrument, which provides the official framework of the governance of plastic pollution.

Moreover, the existing regulations can also be regarded as the guidelines of controlling the marine plastic debris. For example, the COP to the Basel Convention cooperated with the International Maritime Organization (IMO), focusing on ensuring that waste discharged from ships—previously falling under the purview of the International Convention for the Prevention of Pollution from Ships (MARPOL) [19].

3.1.2 Regional Practice

Additionally, in different regions and areas, more adapted plans and strategies are required to meet the regional social and geographical conditions. Although these regional conventions only accommodate to specific scope, they still can be regarded as significant and influential reference in developing global regulation of managing marine plastic pollution [19]. The Regional Plan on Marine Litter Management in the Mediterranean is a considerable example, which is approved by the twenty-second session of the Conference of the Parties (COP22) [20]. The Regional Plan covers both sea- and land-based sources of marine wastes, and it also can be applied on the plastic waste [19].

3.1.3 Local Participation

However, plastic has been deeply and widely related to people's daily life, which would be hardly altered. Therefore, compared to the official and governmental agencies, non-governmental organizations (NGOs) can be placed at a crucial status within the reduction of marine plastic pollution, as they have more remarkable flexibility and independence [21].

2.4 Technical Governance Mechanisms

3.2.1 Recycling and Cleaning Technology

In the governance frameworks for marine plastic waste, technological solutions serve as the cornerstone of management, tackling both mitigation and prevention efforts. With the high speed development of technology recently, more advanced technologies are introduced to the management of marine plastic pollution. For instance, the intelligent robot technology takes a crucial duty in collecting and cleaning the plastic waste in the ocean [17]. Compared with humanpower, the intelligent robot has the ability of moving more flexible and convenient; it can follow the procedure to identify and collect the marine waste in higher efficiency. Moreover, PlasticNet is a project for classifing the plastics, which utilizes convolutional neural networks to classify polymer types with 92% accuracy, streamlining recycling of mixed waste streams [22].

3.2.2 Degradation and Decomposition Technology

The process of degradation of plastic wastes can be commonly explained by breaking the polymeric structure of plastics in either biotic or abiotic methods. Some features like ocean environment and the physicochemical polymeric characteristics of the plastic waste are the influential factors in the breakdown of plastic [23]. For example, the incorporation of heteroatoms into their chain reduces their resistance. As nonpolar molecules are less able to degrade, the polarity of the polymer significantly influences the rate at which it breaks down [24].

The first method is photo-oxidative degradation, using the rays of the sun, including ultraviolet (UV) rays from 280nm to 400nm [24], which are capable to break the polymer chains. And polymers' electrons can be more active and move to a higher state when they seize high energy rays from the UV spectrum. This triggers a process that cause fission, oxidation, and end up with the degradation of the polymer.

The second way is using the Ozone(O3), which can form reactive oxidation species (ROS) [25]. By changing the properties of the polymer with the usage of ROS, it will lead to lower molecular weight and the composition of the polymer alters, resulting in plastic degradation [24].

There are other approaches such as mechanochemical degradation, which changes the ratio of double bonds to other bonds in the polymer, and the ways using catalytic and bio-based systems [24]. However, the actual situation of plastic degradation still needs further exploration. For instance, PLA is now facing challenges in marine environments due to its requirement for industrial composting conditions y. A study found that PLA films submerged in seawater showed only 3% mass loss after one year, highlighting the gap between lab claims and world performance [26].

3.2.3 Pollution Source Control Technology

Not only in degrading the existing plastic waste in ocean, the technical governance also can devote to the replacement of the plastics with environment friendly materials. For example, U.S. company Algenist produces packaging materials from algae-derived polysaccharides, reducing carbon footprints by 60% compared to conventional plastics. Similarly, Sweden's BillerudKorsnäs has commercialized FiberForm, a fully biodegradable paper-based material with mechanical strength comparable to PE in plastics [27]. Furthermore, the application of big data and AI technology enables the prediction of the trends and the analysis of the distribution of marine plastic wastes, thereby giving a systematic foundation for formulating directed control tactics.

3.3 Public Education and Social Participation Mechanisms

Public support is a key part in effective management of marine plastic governance. In recent years, the public has paid much more attention on this task, and the envi-

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ronmental awareness also has increased significantly. A survey shows that over 80% of respondents are concerned about marine plastic pollution and willing to engage in environmental protection activities [17]. Additionally, with the wide application of social media, its promotional effect on the public should not be underestimated. For example, the #SaveTheReefs campaign rallied more than 100,000 volunteers globally for beach cleaning activities in 2019. As a result, approximately 500 tons of plastic pollution was cleared from maritime regions [28]. In raising the awareness of environmental protection among public, the effect of social media is still increasing significantly, contributing to the public education and providing a platform for academic conmunication.

4 Conclusion

The governance of marine plastic waste is one of the severe global environmental tasks. This issue requires the multi-stakeholder coordination of technological innovation, policy frameworks and societal engagement. Technical mechanisms, such as AI-driven sorting and chemical recycling, offer scalable solutions but face challenges in efficiency and environmental compatibility. Policy and legal efforts, including the UNEP's 2022 plastic pollution resolution and regional initiatives, demonstrate the effectiveness of international and regional cooperation, though fragmented performance and liability for transboundary harm issues persist. Societal participation models, for example, the NGO-led cleanup programmes, highlight the importance of public actions in reducing plastic waste. The study reveals that gaps remain in technology expandability, behavioral change, and corporate responsibility, despite progress having been made in understanding sources and distributing patterns of marine plastics. This research emphasizes the critical need for integrated, adaptive governance strategies that bridge the gap between legal regulations and practical actions, fostering a circular economy to mitigate ecological and health risks. By giving priority to collaborative innovation and policy feasibility, humanity can chart a sustainable path toward reversing marine plastic degradation and safeguarding ocean ecosystems for future generations.

References

[1] IUCN. (2024). MARINE PLASTIC POLLUTION. In IUCN Website IUCN Issues Briefs. https://www.iucn.org/sites/default/files/2024-04/marine-plastic-pollution-issues-brief_nov21-april-2024-small-update_0.pdf

[2] Rocha-Santos T.A.P. Editorial overview: Micro and nanoplastics. Curr. Opin. Environ. Sci. Health. 2018; 1:52–54. doi: 10.1016/j.coesh.2018.01.003.

[3] Bertolazzi, S., Cuttitta, A., & Pipitone, V. (2024). Addressing marine plastic pollution: a systematic literature review. Current Opinion in Environmental Sustainability, 68, 101428. https://doi.org/10.1016/j.cosust.2024.101428

[4] Fonseca, T., Agostinho, F., Pavão, J. M. S. J., Sulis, F., Maceno, M. M. C., Almeida, C. M. V. B., & Giannetti, B. F. (2024). Marine plastic pollution: A systematic review of management strategies through a macroscope approach. Marine Pollution Bulletin, 208, 117075. https://doi.org/10.1016/j.marpolbul.2024.117075

[5] Wright, S. L., Thompson, R. C. (2013). The physical impacts of microplastics on marine organisms: A review. Environmental Pollution, 178, 483–492. https://doi.org/10.1016/j.envpol.2013.02.031

[6] Jain, R., Gaur, A., Suravajhala, R. (2023). Microplastic pollution: Understanding microbial degradation and strategies for pollutant reduction. The Science of the Total Environment, 905, 167098. https://doi.org/10.1016/j.scitotenv.2023.167098

[7] Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., .. & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771. DOI: 10.1126/science.1260352

[8] Yang H, Chen G, Wang J. Microplastics in the Marine Environment: Sources, Fates, Impacts and Microbial Degradation. Toxics. 2021 Feb 22;9(2):41. doi: 10.3390/toxics9020041. PMID: 33671786; PMCID: PMC7927104.

[9] Sheavly, S.B., Register, K.M. Marine Debris & Plastics: Environmental Concerns, Sources, Impacts and Solutions. J Polym Environ 15, 301–305 (2007). https://doi.org/10.1007/s10924-007-0074-3

[10] Piccardo, M., Renzi, M., & Terlizzi, A. (2020). Nanoplastics in the oceans: Theory, experimental evidence and real world. Marine Pollution Bulletin, 157, 111317. https://doi.org/10.1016/j.marpolbul.2020.111317

[11] Bhattacharya, A., et al. (2022). Impact of microplastics on marine organisms and potential implications for human health. Environmental Science & Technology, 56(12), 8070–8085. https://doi.org/10.1021/acs.est.1c07973

[12] Rist, S., et al. (2022). Detection and quantification of 12 types of plastic particles in human blood. Environment International, 163, 107199. https://doi.org/10.1016/j.envint.2021.107199

[13] Ryan, P. G., et al. (2018). Microplastics in surface waters of the Southern Ocean. *Nature Communications*, 9(1), 1–9. DOI: 10.1038/s41467-018-03606-4

[14] WWF (World Wildlife Fund). (2020). *Mediterranean Plastics Report*. Gland, Switzerland: WWF. URL

[15] Lebreton, L. C. M., et al. (2020). Quantifying global plastic waste leakage into the ocean from mismanaged waste in coastal megacities. *Environmental Research Letters*, 15(2), 024011. DOI: 10.1088/1748-9326/ab65ec

[16] Jamieson, A. J., et al. (2019). Microplastics in the deepest ocean trenches: evidence for accumulation with potential ecological implications. Nature Ecology & Evolution, 3(2), 265–272. DOI: 10.1038/s41559-018-0745-9

[17] Yang, Y. & Jiangsu Ocean University. (2024). Marine plastic pollution: current situation, impacts, and governance strategies. Advance in Marine Science and Technology, 1–10. https://doi.org/10.26855/amst.2024.12.001

[18] United Nations Environment Assembly. (2022). Resolution adopted by the United Nations Environment Assembly on 2 March 2022. United Nations Environment Assembly of the United Nations Environment Programme. https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/39764/END%20PLASTIC%20POLLUTION%20-%20TOWARDS%20AN%20INTERNATIONAL%20LEGALLY%20BINDING%20INSTRUMENT%20-%20English.pdf?sequence=1&isAllowed=y

[19] Jung D. An International Legal Framework for Marine Plastics Pollution: Time for a Change to Regulate the Lifecycle of Plastics. In: Platjouw FM, Pozdnakova A, eds. The Environmental Rule of Law for Oceans: Designing Legal Solutions. Cambridge University Press; 2023:46-57.

[20] The Marine Litter MED II Project (2020-2023) | UNEPMAP. (n.d.). https://www.unep.org/unepmap/what-we-do/projects/MarineLitterMED-II#:~:text=The%20Marine%20Litter%20MED%20II%20project%2C%20funded%20by,Algeria%2C%20Egypt%2C%20Israel%2C%20Lebanon%2C%20Libya%2C%20Morocco%2C%20and%20Tunisia.

[21] Cui, Y. The difficulties and path of China's NGOs participating in marine plastic waste governance. Mar Dev 2, 8 (2024). https://doi.org/10.1007/s44312-024-00020-7

[22]Ibm. (n.d.). GitHub - IBM/PlasticNet: Computer Vision for the Greater Good. GitHub. https://github.com/IBM/PlasticNet

[23] Zheng, Y., Yanful, E.K., Bassi, A.S., 2005. A review of plastic waste biodegradation. Crit. Rev. Biotechnol. 25 (4), 243–250. https://doi.org/10.1080/07388550500346359.

[24] Gilani, I. E., Sayadi, S., Zouari, N., & Al-Ghouti, M. A. (2023). Plastic waste impact and biotechnology: Exploring polymer degradation, microbial role, and sustainable development implications. Bioresource Technology Reports, 24, 101606. https://doi.org/10.1016/j.biteb.2023.101606

[25] Kefeli, A., Razumovskii, S., & Zaikov, G. (1971b). Interaction of polyethylene with ozone. Polymer Science U S S R, 13(4), 904–911. https://doi.org/10.1016/0032-3950(71)90288-7

[26] Shen, M., Song, B., Zeng, G., Zhang, Y., Huang, W., Wen, X., & Tang, W. (2020). Are biodegradable plastics a promising solution to solve the global plastic pollution? Environmental Pollution, 263, 114469. https://doi.org/10.1016/j.envpol.2020.114469

[27] FIBREFORM. (n.d.-b). PACKAGING INNOVATION. In FIBREFORM. https://www.billerud.se/globalassets/billerudkorsnas/our-offer/packaging-solutions/formable-solutions/fibreform-packaging-innovation-folder.pdf

[28] Singh, A. (2025, February 20). How social media transformed marine conservation (And why it matters). Marine Biodiversity Science Center. https://www.marinebiodiversity.ca/how-social-media-transformed-marine-conservation-and-why-it-matters/