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A Fact File on

MARINE POLLUTION

[A Joint Publication of the NAM S&T Centre; Center for Sustainable Ocean Policy, Universitas Indonesia; and Non-Aligned Movement Centre for South-South Technical Cooperation (NAM CSSTC)]

FROM THE DG'S DESK

Warmest Greetings to our Esteemed Readers!

I am pleased to present before you the latest Fact File titled "Marine Pollution" published by the NAM S&T Centre; in collaboration with the Centre for Sustainable Ocean Policy (CSOP), Universitas Indonesia; and the Non-Aligned Movement Centre for South-South Technical Cooperation (NAM CSSTC), Jakarta, Indonesia.

This Fact File is a concise document that provides an overview of Marine Pollution, which is one of the most serious environmental challenges of our time; and also gives an outline of the threat that extends beyond the degradation of marine ecosystems. The document delves into the degradation of vital ecosystems, threats to food security and public health, and the limitations of current international legal frameworks like MARPOL, UNCLOS and the London Protocol. Particularly noteworthy are the technological and legislative innovations featured in this Fact File, including AI-based pollution tracking systems, biodegradable solutions and pioneering initiatives like the Ocean Cleanup and ASEAN's regional action plans.

This Fact File is not only an informative document but also a reminder for action by governments, industries, scientists and citizens to reaffirm our shared responsibility toward a sustainable future where marine ecosystems can thrive in harmony with human development.

I would like to express my sincere gratitude to Dr. Arie Afriansyah, Chair, CSOP, and Professor of International Law, Faculty of Law, Universitas Indonesia, for his valuable contributions as the Chief Contributor and Scientific Editor. I also extend my heartfelt thanks to H.E. Ambassador Diar Nurbintoro, Director, NAM CSSTC; and Mr. Madhusudan Bandyopadhyay, Senior Advisor, NAM S&T Centre for their guidance and support as Editorial Advisers.

We are also hopeful that the Fact File will enhance our understanding and appreciation of the UN Sustainable Development Goal 14 (Life Below Water).

(Amitava Bandopadhyay)

1. Overview

Marine pollution is a growing global crisis with severe environmental, social and economic repercussions. It threatens marine biodiversity, degrades critical ecosystems like coral reefs, mangroves seagrass beds and also endangers coastal communities reliant on marine resources. Pollutants from industrial waste, plastics and chemicals accumulate in marine organisms, posing serious health risks to marine life and humans. Beyond environmental damage, marine pollution jeopardizes food security, economic stability and public health. The destruction of coral reefs and mangroves leads to decline in fish stocks, harming millions dependent on fisheries, while tourism industries suffer economic losses due to pollution-related environmental degradation. Despite international agreements like MARPOL, UNCLOS and the London Protocol, weak enforcement, inadequate waste management and pollution's transboundary nature hinders effective regulation. Scientific advancements, including AI-based pollution monitoring and bioengineered plastic-degrading microorganisms, offer promising solutions but require stronger global commitment. This article comprehensively examines the impacts of marine pollution, legal frameworks and technological solutions, analysing enforcement challenges through case studies. By integrating scientific and legal perspectives, it advocates for enhanced international cooperation and innovative strategies to combat marine degradation.

2. Impact on Environment and Society

2.1. Environmental Impacts

Marine pollution severely threatens coastal ecosystems, including coral reefs, mangrove forests and seagrass beds which are vital for biodiversity and human livelihoods. Pollution from industrial waste, plastics and chemicals has accelerated ecosystem degradation, endangering natural resources. Coral reefs, often called the "underwater tropical rainforests," support over 25% of marine species and protect shorelines from erosion. However, pollutants like microplastics and pesticides disrupt coral growth, weaken structures and cause bleaching, leading to habitat loss. The Reefs at Risk Revisited report (2021) states that 75% of the world's coral reefs are now threatened. Similarly, mangrove forests which filter pollutants and prevent erosion are declining due to industrial and agricultural waste, reducing biodiversity and limiting carbon absorption. Seagrass beds, essential for fish and mollusks also suffer from pollution, disrupting the marine food chain and impacting fisheries. This ecosystem decline threatens marine biodiversity and the livelihoods of coastal communities dependent on fishing and tourism.

Beyond habitat destruction, marine pollution causes toxic bioaccumulation, invasive species spread and ecosystem imbalances. Harmful chemicals like PCBs and pesticides enter the marine food chain, accumulating in fish such as tuna and sharks, posing health risks to marine life and humans. These toxins affect reproduction, weakening species populations and disrupting biodiversity. Additionally, pollution enables invasive species to spread via plastic debris, threatening native ecosystems. A notable case is the Atlantic Ocean Lionfish which aggressively displaces local species due to ship movement and plastic waste. These disruptions highlight the urgent need for stronger global pollution control and conservation efforts.

2.2. Social and Economic Impacts

Marine pollution severely impacts global fish populations, leading to declining fish catches and threatening food security. The destruction of coral reefs and coastal habitats, combined with the bioaccumulation of toxins in fish, reduces fish stocks which are crucial to millions worldwide. The FAO

(2022) reports that over 3.3 billion people, especially in developing nations, rely on fish as their primary protein source. Toxic pollutants disrupt fish metabolism, reproduction, and immune systems, causing lower birth rates and higher mortality. Coastal communities, particularly in the Philippines, have experienced a 30% decline in fishery yields over two decades due to plastic waste, directly affecting their livelihoods. Additionally, the degradation of seagrass beds and mangrove forests further diminishes fish habitats, worsening the sustainability of coastal fisheries.

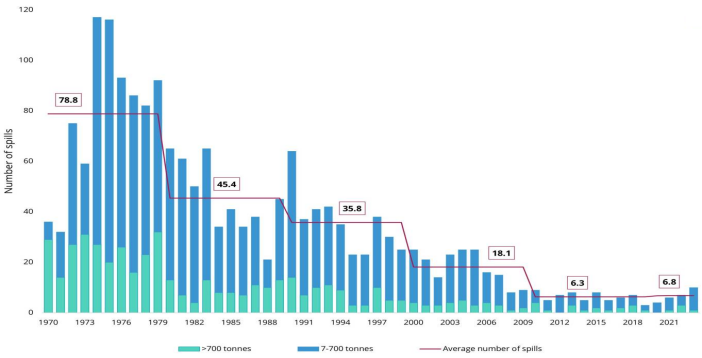
Beyond fisheries, marine pollution threatens coastal tourism, local economies and public health. Polluted beaches and contaminated seawater drive tourists away, causing financial losses. A study in Bali found that plastic pollution led to a 15% drop in tourism in 2020, affecting businesses like hotels and restaurants. Since global tourism contributes 10% to the world's GDP, such losses are critical for economies dependent on coastal tourism. Additionally, exposure to marine pollutants causes serious health issues, including infections, digestive disorders and seafood poisoning. WHO estimates 1.7 million illnesses annually due to toxic ocean pollution, with coastal communities most affected. Developing nations with limited healthcare systems struggle to address these growing health concerns, worsening socio-economic inequalities.

3. Relevant International Frameworks

3.1. United Nations Conventions

3.1.1 The International Convention for the Prevention of Pollution from Ships.

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the leading international convention that addresses pollution from ships primarily from operational pollution, be it of an intentional or negligent nature. This convention includes six technical annexes. Naturally, as this convention was mainly adopted as a response to several oil tanker spills between 1976 and 1977, one of the first technical annexes introduced was about preventing ocean oil pollution. The impact of MARPOL can be seen in the significant reduction of oil tanker spills, as charted by The International Tanker Owners Pollution Federation Limited below:



Number of medium (7-700 tonnes) and large (>700 tonnes) tanker spills, 1970 - 2023

Figure 1: Oil Spills from Ships

Source: https://www.itopf.org/knowledge-resources/data-statistics/oil-tanker-spill-statistics-2024/

Besides oil spills, MARPOL also regulates the carriage of potentially harmful substances apart from oil by sea. These include the rest of the five technical annexes (II-VI), which are about Noxious Liquid Substances in Bulk, Harmful Substances Carried by Sea in Packaged Form, Sewage from Ships, Garbage from Ships, and Air Pollution from Ships, respectively. These annexes are very technical (down from labelling, packaging, ship specifications, etc.) and differentiate between the discharge of substances, including oil, in general and special areas. The enforcement of this convention is done in at least two significant leaps in the international legal framework for one of the three main actors of the sea at the global level, the port state. The convention boosts port state control by giving it the power to inspect ships and report evidence of a breach of MARPOL outside of its waters to the flag state, as well as the approval to inspect vessels for seaworthiness and detain them until the deficiencies fixed.

3.1.2 The United Nations Convention on the Law of the Sea.

The 1982 United Nations Convention on the Law of the Sea (UNCLOS 1982) laid down the definition of marine pollution as “the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for the use of seawater and reduction of amenities” as stated in Article 1 (4). UNCLOS 1982 Part XII primarily deals with protecting marine life in the ocean by acknowledging that all states must protect the marine environment. Such duties extend from the broad obligation given by the convention to protect and preserve the marine environment and minimise marine pollution.

Not to mention, there are more specific obligations entailed in the convention, such as the mandate to cooperate on a global and regional basis for the goal of formulating environmental standards elaborately, notifying other states of imminent danger (whatever it may be defined as in the convention) of pollution damage, jointly develop contingency plans to respond to pollution incidents, endeavour in scientific research and information exchanges, provide scientific and technical assistance to less developed states, monitor the risks and effects of pollution and perform environmental assessments. Even though Article 193 of UNCLOS 1982 laid down the obligation of party states to exploit their natural resources in accordance with their national environmental policies and duty to protect and preserve the marine environment, this duty is defined in standards that could hardly be called international measures at all as the term used is “*national laws and regulations not less effective than international measures”* with no clear rule on who judges such effectiveness in the first place.

3.1.3 The 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972

The 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (London Protocol 1996) is built upon the insight of the London Convention of 1972 and improves upon every aspect of it. They both provide the global legal framework for protecting the marine environment against pollution from dumping waste at sea, as implied in the UNCLOS 1982. As of 2010, the London Convention of 1972 and the London Protocol of 1996 represent 67% and 33% of global merchant shipping tonnage in terms of state parties. The London Protocol - Article 2 states its objective as eliminating pollution caused by dumping or incineration at sea of wastes or other matter wherever practicable. Consistent with global initiatives such as the Rio Principles, Article 3 of the London Protocol puts forth the precautionary approach and the polluter-pays principle.

Consistent with the objectives in Article 2, Articles 4 and 5 directly prohibit dumping and incineration at sea, with general exceptions such as securing human life's safety in emergencies. The London Protocol 1996 cheats its way around the London Convention Article 15 entry into force requirement by using Article 23 of the protocol stating, “*This protocol will supersede the Convention as between Contracting Parties to the protocol which are also Parties to the Convention*”standards? The 14th Consultative Meeting is considered to have established the London Convention as one of the key standards. Consequently, as the London Protocol is ultimately designed to replace the London Convention, it is not too far a stretch to assume that it is one of those global standards in Article 210 of UNCLOS.

3.2. Global Initiatives

The UN Sustainable Development Goals (SDGs), particularly Goal 14.1, aim to reduce marine pollution by 2025, aligning with the broader objectives of the Millennium Development Goals (MDGs) and the 2030 Agenda. SDG 14, focused on life below water, represents a major advancement in global ocean sustainability policy, with seven targets and three sub-targets addressing marine pollution, overfishing, and conservation. Since its conception

by Pacific Small Island Developing States, SDG 14.1 has inspired numerous global initiatives funded by governments, private sectors or both. Various scientific approaches have been developed to combat marine pollution, generally categorized into three action points. Private-public partnerships, such as the AXA Research Fund, Meer Wissen Initiative and ArcticNet, have supported these efforts under the UN Decade of Ocean Science for Sustainable Development. Additionally, non-governmental initiatives like Team Seas, led by content creators Mr. Beast and Mark Rober have removed over 30 million pounds of ocean waste through social media-driven fundraising campaigns.

Launched in 2021, the UN Decade of Ocean Science for Sustainable Development provides a global framework for advancing ocean sustainability through research and policy. Spearheaded by UNESCO's Intergovernmental Oceanographic Commission (IOC-UNESCO), this initiative fosters "Decade Actions" - projects and programs endorsed every six months to drive impactful ocean management strategies. While these discussions promote necessary commitments toward a pollution-free ocean with a thriving ecosystem, the financial resources required to implement the envisioned projects remain a significant challenge. Securing sufficient funding remains a major obstacle in translating these commitments into meaningful actions.

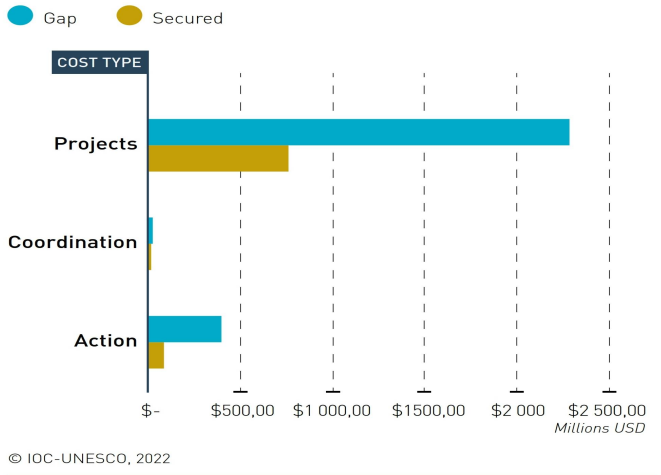


Figure 2: Ocean Decade Progress Report 2021–2022

Source: UNESCO-IOC (2022). Ocean Decade Progress Report 2021–2022.

Many efforts to secure engagements, stakeholders and awareness in this movement have been made through social media, the “Global Stakeholder Forum”, public campaigns like GenOcean and various media partnerships. Nevertheless, this global framework is a milestone in the gathering of the global ocean community. It allows scientists and think tanks to promote and collaborate on research and technological breakthroughs to fulfil the UN SDG.

4. Mitigation and Solutions

Marine pollution, including oil spills, chemicals, plastics and noise which harms marine ecosystems, coastal communities and human health. Preventing future pollution is as crucial as managing existing waste. Effective solutions require both scientific approaches and legal policies to mitigate and resolve this growing environmental threat.

4.1. Scientific Approaches

Technological advancements play a vital role in tackling marine pollution. Wastewater treatment helps filter microplastics from urban and industrial waste before they reach the ocean, reducing harmful contaminants. Recycling technologies, like those used by Licella Holdings in Australia, convert plastic waste into valuable materials such as oil, ensuring continuous reuse. Promoting biodegradable materials and reducing single-use plastics is also essential. With plastic waste projected to reach 26 billion tons by 2050, transitioning to biodegradable alternatives can prevent long-term environmental damage.

Additionally, artificial intelligence and satellite imaging enhance marine pollution monitoring and response. These technologies track oil spills, monitor vessel navigation and assess seawater cleanliness. NASA's Cyclone Global Navigation Satellite System (CYGNSS) has been detecting ocean plastic concentrations since 2016, improving pollution management. Combining waste treatment, recycling, biodegradable materials and advanced monitoring technologies are key to mitigating marine pollution and preserving ocean ecosystems.

4.2. Legal and Policy Recommendations

Strengthening legal frameworks and policy enforcement are essential in mitigating marine pollution. UNCLOS 1982 mandates that member states protect and preserve the marine environment (Article 192), which can be reinforced through national policies regulating industrial discharges and promoting sustainable practices. For example, the U.S. Clean Water Act empowers the EPA to regulate water pollutants, while Indonesia's Presidential Regulation No. 109 of 2006 mandates responsibilities for oil spill emergencies. Economic incentives like subsidies for eco-friendly practices and fines for violators can enhance compliance, aligning with Article 193 of UNCLOS, which grants states autonomy in pollution prevention but requires coordination among government agencies, law enforcement and technology availability.

Regional agreements further strengthen marine pollution control by harmonizing policies among neighbouring countries. The Nairobi Convention in Eastern Africa provides a framework for managing shared marine environments, while the OSPAR Convention in Northern Europe focuses on biodiversity, hazardous substances and climate change. Such agreements encourage collaboration in scientific research, policymaking and restoration projects, thus promoting sustainable water and habitat management. If each region effectively enforces its agreements, global marine pollution control can be significantly improved, ensuring better environmental governance and long-term protection of marine ecosystems.

5. Challenges of Marine Pollution

5.1. Scientific Challenges

Research on marine pollution remains limited in many regions due to the complexity of environmental systems and the scarcity of localized data. The open nature of ecological systems introduces uncertainty, making it difficult to draw definitive conclusions. Many areas lack comprehensive data on pollution sources, distribution and impacts. For instance, studies on microplastic pollution in the Gulf region account for only 1.1% of global research despite extensive industrial activity. Similarly, Indonesia, a major contributor to marine plastic pollution, lacks empirical evidence of its effects on ecosystem services and human health.

Microplastics and chemical toxins present further challenges to food security and environmental health. These particles in soil, water and air carry hazardous chemicals like heavy metals, harming both marine life and humans. Their small size, diversity and resistance to degradation complicate detection, quantification and removal. Additionally, inadequate waste management infrastructure exacerbates pollution, especially in Small Island Developing States (SIDS) and developing nations. Limited financial and technical resources hinder effective waste collection, transportation and recycling, thus further worsening plastic pollution and posing long-term threats to ecosystems and human well-being.

5.2. Legal Challenges

Despite numerous legal instruments addressing marine pollution, such as MARPOL, UNCLOS and the London

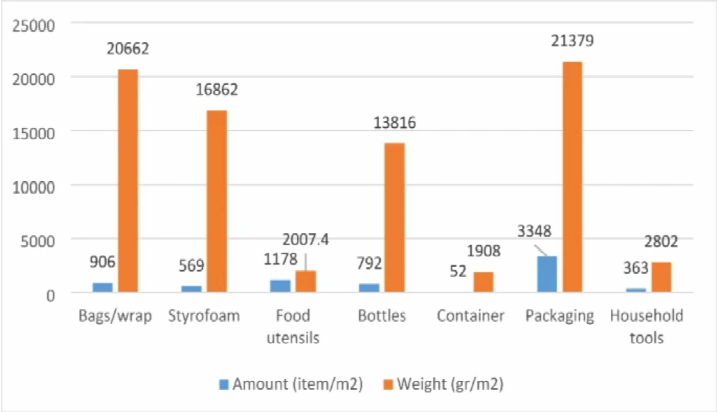


Figure 3: The Type of Plastic Waste found in Jakarta Bay

Source: https://doi.org/10.1007/s11852-022-00888-x.

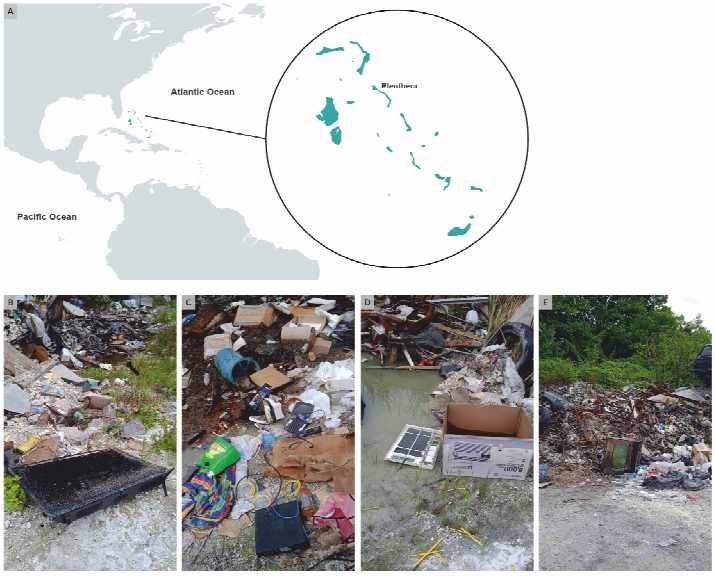


Figure 4: Dumping sites in the Deep Creek and Waterford Settlements, located in the Southern Region of Eleuthera Island, The Bahamas

Source: https://doi.org/10.3389/fmars.2024.1459794.

Convention, their enforcement remains weak due to the decentralized nature of international law. While these conventions establish sanctions and compliance measures, violations persist due to complex legal language, low public awareness and inconsistent enforcement. Many vessels operate under "flags of convenience" in states with minimal environmental regulations, such as Panama and Liberia, exploiting legal loopholes to avoid stricter compliance. This regulatory gap highlights the challenges in ensuring uniform adherence to international marine pollution laws.

At the national level, enforcement gaps further weaken pollution control. In Indonesia, multiple regulations, including Law No. 32 of 2009 on Environmental Protection and Law No. 18 of 2008 on Waste Management, lack clear enforcement mechanisms, leading to inconsistent penalties. The ongoing pollution issue in Pulau Pari exemplifies this weakness. Transboundary marine pollution presents another challenge, as jurisdictional complexities and differing national policies hinder a uniform response. Disputes over liability, such as using oil dispersants in the Barents Sea by Norway and Russia, demonstrate the difficulty in establishing clear accountability, complicating global marine pollution mitigation efforts.

6. Innovations and Legislative Initiatives

Various organisations and countries have developed numerous approaches to address the ongoing problems of marine pollution. These include crafting technological innovations such as deploying ocean-cleaning technologies to remove surface debris, engineering microorganisms to break down plastics and toxins and establishing regional research hubs to analyse pollution, develop mitigation strategies and create new acts that minimise marine pollution. To explore these solutions further, the following sections provide a detailed overview of technological innovations, scientific research and legislative initiatives to mitigate marine pollution.

6.1. Technological Innovations

Technological innovations are the development of new or improved technologies, products, services, or processes that lead to significant advancements in various fields to improve the quality of life. In environmental science, mainly marine science, marine pollution is one of many critical global environmental concern.

One of the ways to mitigate the impact is by utilising technological innovations created by various organisations like Ocean Cleanup. The Ocean Cleanup is a non-profit environmental organisation founded in 2013 by Boyan Slat that develops and deploys multiple innovative technologies, both ocean-based and river-based systems to reduce waste from rivers and oceans. They deployed their latest and most advanced ocean cleanup technology named the 'System 03', a U-shaped floating barrier towed by ships. It can capture plastic debris using a floating 2.5-kilometre-long barrier that funnels plastic into a retention zone, where captured debris is stored until recycled. Ocean Cleanup's technologies have proven to be significantly efficient in cleaning rivers and oceans. As of late 2023, 'System 03' has successfully collected over 10 million kilograms of plastic from the ocean, featuring 45 tons of plastic in a single trip.

Another way to minimise marine pollution is by bioengineering microorganisms that degrade plastics and toxins. Microorganisms, such as bacteria, fungi and even some invertebrates, have been identified as effective agents for the biodegradation of various plastics. The discovery was made in 1975 when a team of scientists discovered that a bacterium identified as *Achromobacter guttatus* could break down nylon in wastewater pools from a nylon factory in Japan. Scientists soon discovered more bacteria and fungi capable of metabolising plastics such as polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC). Researchers worked on modifying existing strains and developing new bacterial consortia by genetic engineering to enhance the efficiency of plastic degradation. The bacterial modifications created by researchers supported the ongoing issue of plastic pollution in specific habitats containing natural polymers and habitats enriched with plastic waste. For example, a research article conducted in 2017 revealed bacterial strains isolated from wax moth or Galleria mellonella larvae had demonstrated rapid plastic degradation capabilities, converting polyethene (PE) into ethylene glycol and reducing the weight of PE film by up to 13% within just 14 hours.

Finally, establishing regional research hubs is essential for analysing pollution sources and developing mitigation strategies to promote collaboration, research capacity, and innovative technologies to protect marine environments. An example of a regional research hub in Indonesia would be the ASEAN Regional Action Plan for Combating Marine Debris. The ASEAN Regional Action Plan for Combating Marine Debris is a coordinated effort initiated by the Association of Southeast Asian Nations (ASEAN) in 2021 to address the issue of marine plastic pollution in the region based on the adoption of the Bangkok Declaration on Combating Marine Debris in the ASEAN Region and the ASEAN Framework of Action on Marine Debris at the 34th ASEAN Summit in June 2019. However, the plan had some challenges in addressing marine pollution. One of the challenges faced in the ASEAN Regional Action Plan is the lack of policymakers' support and involvement in implementing the ASEAN policy. Many regions in Indonesia still rely on inefficient waste management methods to handle the growing volume of plastic waste and many ASEAN countries do not have the local capacity to reduce plastic waste in the ocean.

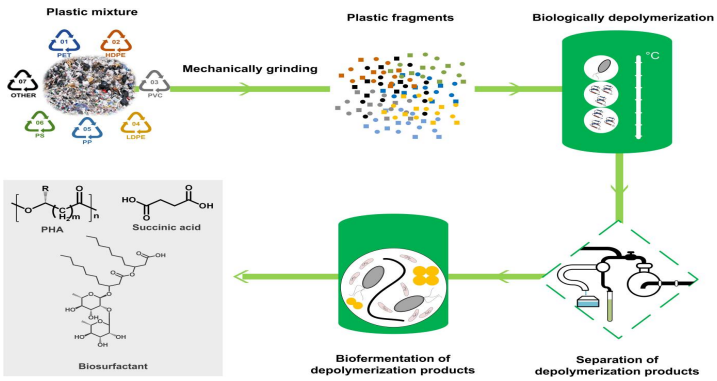


Figure 5: The basic conception of Bio-upcycling Plastic Waste

Source: https://doi.org/10.3389/fmicb.2020.00442.

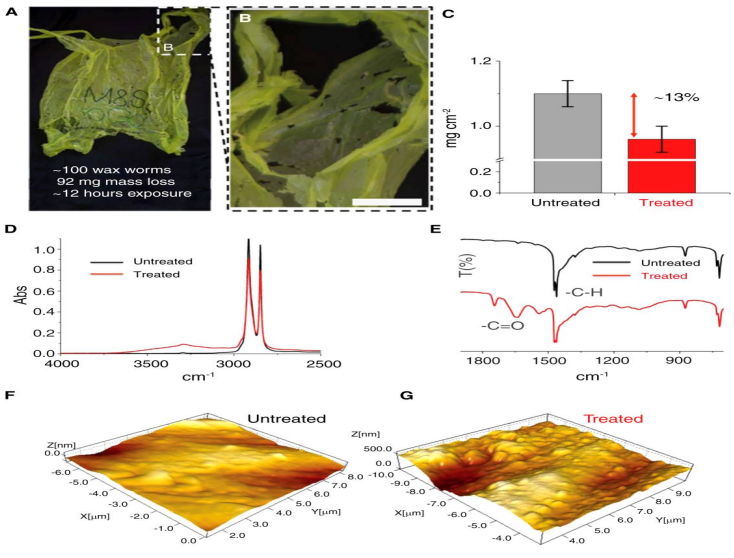


Figure 6: Polyethylene degradation by *Galleria mellonella*

Source: https://doi.org/10.1016/j.cub.2017.02.060.

6.2. Legislative Initiatives

Legislative initiatives can propose new laws and bills to legislature. This plays a crucial role in democratic governance by allowing stakeholders to propose new laws and bills, irrespective of their positions. Numerous countries have proposed laws and have taken actions, like Kenya's Plastic Bag Ban Notice No. 2356 in The Environmental Management and Coordination Act and Indonesia's National Action Plan on Marine Debris.

Kenya's Plastic Bag Ban Notice No. 2356 (Plastic Bag Ban on Secondary Packaging) in The Environmental Management and Coordination Act is formalised through Gazette Notice No. 2356 on February 28, 2017. The ban targets using, manufacturing and importing plastic bags for commercial and household packaging, except garbage bin liners, medical waste, construction and food packaging. Those caught manufacturing or using plastic bags face up to four years in jail or a fine of up to 4.4 million Kenyan shillings. The ban is legally binding; the government enforces it, and penalties for violations will be received. According to the National Environment Management Authority of Kenya (NEMA), the ban was successful with an 80% decrease in single-use plastic bags.

Another legislative initiative passed is Indonesia's National Action Plan on Marine Debris, established through Presidential Decree Number 83/2018. The decree serves as the legal foundation for the National Action Plan for combating marine pollution, where they set an ambitious target to reduce marine plastic debris by 70% by 2025 by the National Action Plan for Marine Debris Management. Despite the decree being voluntary, charges for plastic bags and river clean-up initiatives such as the Citarum River clean-up have been introduced, and some developments have included the use of plastic for asphalt roads.

7. Conclusion

Marine pollution is a major environmental crisis affecting biodiversity, human health, and economic stability. It threatens marine ecosystems, reduces fishery yields, harms tourism and increases healthcare costs. Despite international conventions like MARPOL and UNCLOS, weak enforcement, regulatory gaps and inconsistent policies hinder progress. Scientific solutions, such as AI-based pollution tracking and plastic-degrading microorganisms, face funding and implementation challenges. Legal measures, including stricter penalties and regional agreements require stronger political commitment. While mitigation efforts are developing, enforcement remains complex. Urgent global action, enforceable regulations, scientific innovation and public awareness are essential to prevent further marine degradation and long-term environmental damage.

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Contributor and Scientific Editor: Dr. Arie Afriansyah, Chair, CSOP, and Professor, Universitas Indonesia **Editorial Advisers:** Ambassador Diar Nurbintoro, Director, NAM CSSTC; and Mr. Madhusudan Bandyopadhyay, Sr. Advisor, NAM S&T Centre **Staff Editor:** Ms. Nidhi Utreja, Programme Officer, NAM S&T Centre **Compilation & Design:** Mr. Pankaj Buttan, Data Processing Manager, NAM S&T Centre **Published by:** Dr. Amitava Bandopadhyay, Director General, Centre for Science & Technology of the Non-Aligned and Other Developing Countries (NAM S&T Centre), Core 6A, 2nd Floor, India Habitat Centre, Lodhi Road, New Delhi-110003 (India)
Phone: +91-11-24645134, 24644974 **E-mail:** namstcentre@gmail.com **Website:** https://www.namstct.org