TAMIL NADU FISHNET INITIATIVE

To reduce marine litter from discarded fishnets

MARINE LITTER ON TAMIL NADU COAST, INDIA

STATUS, IMPACTS AND MANAGEMENT STRATEGIES

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Tamil Nadu Pollution Control Board
In partnership with
SDMRI, PwC and Recity

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The coasts of Tamil Nadu face a silent threat from marine litter. Abandoned and discarded fishing gear endangers marine life, degrades habitats, and undermines the livelihoods of coastal communities. Protecting our oceans is not just an environmental duty, but it is our responsibility to future generations.

Thiru **M.K. STALIN**
Honourable Chief Minister of Tamil Nadu

The ocean health and the sustainability of fisheries face threat from marine litter, particularly discarded fishing gear and plastics. The Tamil Nadu Fishnet Initiative (TNFI) sets itself apart as a pioneering effort in marine conservation by actively involving the local community in the collection of discarded nets and other ocean-bound plastics.

Thiru **THANGAM THENNARASU**
Honourable Minister for Finance,
Environment and Climate Change, Tamil Nadu

Marine litter is not just waste, it reflects unsustainable practices. Focused strategies informed by scientific assessment, supported by policy, and with community participation provide actionable insights to guide sustainable solutions, strengthen coastal ecosystems, and align state action with national and global marine conservation goals.

Tmt. **SUPRIYA SAHU, IAS**
Additional Chief Secretary to Government,
Environment, Climate Change and Forest
Department, Tamil Nadu

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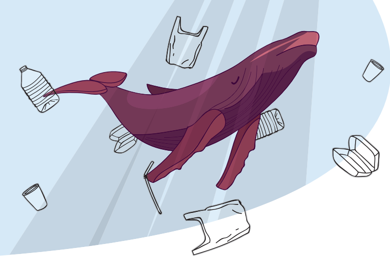
The Tamil Nadu Pollution Control Board through its unique and novel Tamil Nadu Fishnet Initiative is addressing marine litter by recovering and recycling discarded fishing nets. The successful pilot Discarded Fishnet Collection Centre at Kasimedu has paved the way for the expansion of this initiative across 14 coastal districts under TN-SHORE (Tamil Nadu Sustainably Harnessing Ocean Resources and Blue Economy) Project for promoting responsible fishing practices and community collaboration.

Dr. JAYANTHI, M., IFS
Chairperson, Tamil Nadu Pollution Control Board



PREFACE

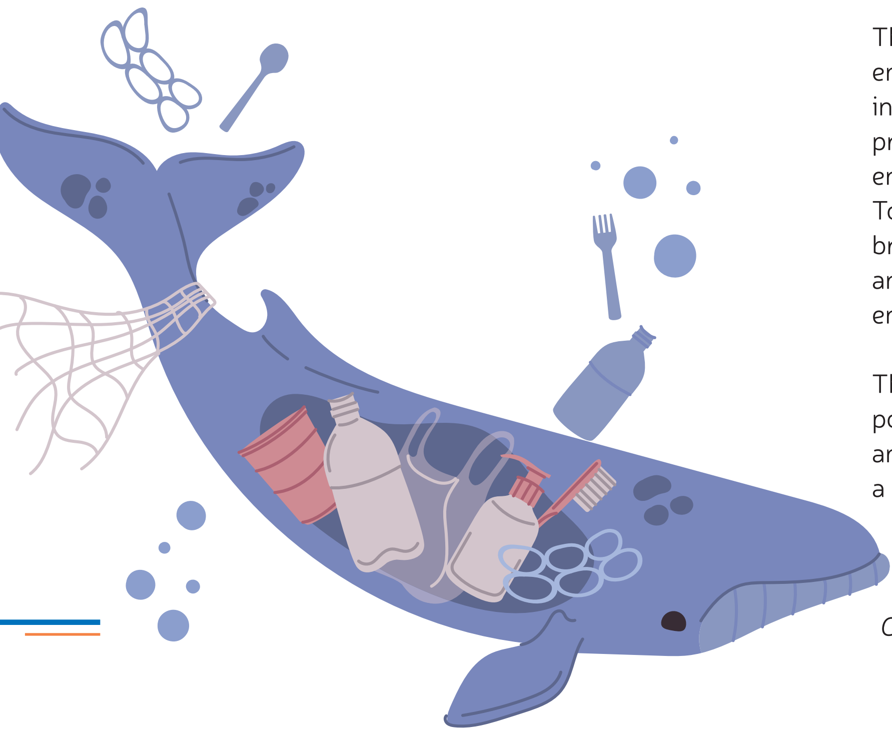
The coastal environment is a vital ecological and economic asset, which supports rich marine biodiversity and sustains the livelihoods of millions, particularly those living near the coast. However, the growing menace of marine litter, especially Abandoned, Lost, and Discarded Fishing Gear (ALDFG) and plastic debris pose significant threats to marine ecosystems, fisheries, and the livelihood of the coastal communities. Addressing this complex challenge requires a scientific, policy-driven, and community-oriented approach.

This report, 'Marine Litter on Tamil Nadu Coast, India: Status, Impacts, and Management Strategies', is the outcome of extensive field research focused on the sources, distribution, and impacts of marine litter along the coastline of Tamil Nadu. Based on systematic shoreline assessments, this report provides critical insights into pollution trends, dominant litter types, and the ecological and socioeconomic implications of marine debris.

The findings presented herein aim not only to enhance academic understanding but also to support real-world solutions. Effective marine litter management calls for coordinated action among government agencies, research institutions, fishing communities, civil society, and the private sector. State-led efforts, such as the Tamil Nadu Fishnet Initiative (TNFI) which promotes the retrieval and recycling of discarded fishing nets through incentivized collection centers, demonstrate the potential of integrated, circular-economy approaches in mitigating ALDFG.

The Key Recommendations offered in this report emphasize strengthening waste management infrastructure, promoting sustainable fishing practices, enhancing producer responsibility, and encouraging participatory clean-up initiatives. Together, these strategies will contribute to broader efforts to reduce marine plastic pollution and ensure the long-term sustainability of marine environments.

This report will serve as a valuable reference for policymakers, environmentalists, researchers, and community stakeholders working toward a cleaner, healthier, and more resilient coastal ecosystems in Tamil Nadu and beyond.



Dr. Jayanthi, M., IFS
Chairperson, Tamil Nadu Pollution Control Board

LIST OF ABBREVIATIONS

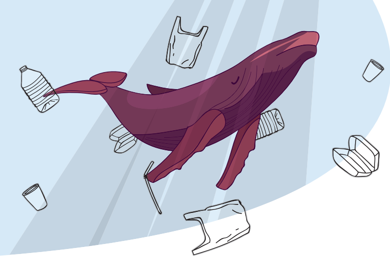
ABBREVIATION	FULL FORM
ABS	Acrylonitrile Butadiene Styrene
ALDFG	Abandoned, Lost or Discarded Fishing Gear
AR	Alkyd Resin
ATR-FTIR	Attenuated Total Reflection-Fourier Transform Infrared Spectroscopy
BEAMS	Beach Environment & Aesthetics Management Services
BOBP	Bay of Bengal Programme
BQI	Beach Quality Index
CCI	Clean Coast Index
CEI	Clean Environment Index
CIFT	Central Institute of Fisheries Technology
CIFNET	Central Institute of Fisheries Nautical and Engineering Training
CMFRI	Central Marine Fisheries Research Institute
CMLRE	Centre for Marine Living Resources and Ecology
COBSEA	Coordinating Body on the Seas of East Asia
CP	Cellophane
CPCB	Central Pollution Control Board
CPR	Continuous Plankton Recorder
CSIR	Council of Scientific and Industrial Research
CSR	Corporate Social Responsibility
CRZ	Coastal Regulation Zone
DFG	Derelict Fishing Gear
DRDO	Defence Research and Development Organisation
EDCs	Endocrine-Disrupting Chemicals
EPA	United States Environmental Protection Agency
EOLFG	End-of-Life Fishing Gear
EPR	Extended Producer Responsibility
EC	European Commission
EEZ	Exclusive Economic Zones
EU	European Union
EVA	Ethylene-Vinyl Acetate
FAO	Food and Agriculture Organization
FAO COFI	FAO Committee on Fisheries

LIST OF ABBREVIATIONS

ABBREVIATION	FULL FORM
FSI	Fishery Survey of India
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GGGI	Global Ghost Gear Initiative
GHG / GHGs	Greenhouse Gas / Greenhouse Gases
GPS	Global Positioning System
GPML	Global Partnership on Marine Litter
HDPE	High-Density Polyethylene
HLI	Hazardous Litter Index
ICAR	Indian Council of Agricultural Research
ICZM	Integrated Coastal Zone Management
IMO	International Maritime Organization
INC	Intergovernmental Negotiating Committee
IOC	Intergovernmental Oceanographic Commission
LDPE	Low-Density Polyethylene
MARPOL	International Convention for the Prevention of Pollution from Ships
MARESSOL	Mannar Region Systemic Solutions
MoEFCC	Ministry of Environment, Forest and Climate Change
MoES	Ministry of Earth Sciences
MoHUA	Ministry of Housing and Urban Affairs
MoPSW	Ministry of Ports, Shipping and Waterways
MOOC	Massive Open Online Course
MPEDA	Marine Products Export Development Authority
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSMEs	Micro, Small, and Medium Enterprises
NAPCC	National Action Plan on Climate Change
NCCR	National Centre for Coastal Research
NCM	National Coastal Mission
NCERT	National Council of Educational Research and Training
NCSCM	National Centre for Sustainable Coastal Management
NGO	Non-Governmental Organization
NIOT	National Institute of Ocean Technology
NMLP	National Marine Litter Policy

LIST OF ABBREVIATIONS

ABBREVIATION	FULL FORM
NOAA	National Oceanic and Atmospheric Administration
PA	Polyamide (Nylon)
PAN	Polyacrylonitrile
PAI	Plastic Abundance Index
PC	Polycarbonate
PCFML	Positive Change for Marine Life
PCoA	Principal Coordinates Analysis
PCA	Principal Component Analysis
PE	Polyethylene
PET	Polyethylene Terephthalate
PFAS	Per- and Polyfluoroalkyl Substances
PIB	Press Information Bureau
PMMA	Polymethylmethacrylate
POPs	Persistent Organic Pollutants
PP	Polypropylene
PS	Polystyrene
PU	Polyurethane
PVC	Polyvinyl Chloride
PVA	Polyvinyl Acetate
PVDF	Polyvinylidene Fluoride
RFID	Radio Frequency Identification
ROVs	Remotely operated vehicles
SBMPL	Sea-based Marine Plastic Litter
SDG	Sustainable Development Goal
SDMRI	Suganthi Devadason Marine Research Institute
SOPs	Standard Operating Procedures
SUP	Single-Use Plastic
TNFI	Tamil Nadu Fishnet Initiative
TNPCB	Tamil Nadu Pollution Control Board
TN SHORE	Tamil Nadu Sustainably Harnessing Ocean Resources and Blue Economy
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNGA	United Nations General Assembly



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KEY MESSAGES

Marine litter is a growing global concern. It encompasses all persistent, manufactured, or processed solid material discarded in the marine and coastal environment. It originates from a variety of land-based sources including plastic waste mismanagement, industrial discharges, and shoreline-based activities such as coastal tourism, port operations, fishing harbor activities, and informal settlements as well as from sea-based sources such as shipping, fishing, aquaculture, and offshore activities.

Depending on where it accumulates, marine litter is categorized as floating litter (on the sea surface), benthic litter (on the seafloor), and beach litter (along the shoreline). Among these, beach litter is the most visible and accessible form of marine litter, deposited by tidal action, wave dynamics, wind transport, and direct human activities such as fishing, beach use and unregulated dumping along the coast. Shoreline surveys of beach litter provide a practical and effective way to collect reliable data that can guide local marine litter management efforts. According to UNEP/IOC (2009), beach litter surveys have long served as primary tools for measuring the marine litter accumulation on beaches, offering not only scientifically valuable data but also opportunities for public education and engagement.

This study highlights beach litter surveys as an important tool in marine litter assessment, using shoreline observations to quantify pollution levels and understand spatial distribution. The surveys were carried out across 52 coastal villages in 13 of Tamil Nadu's 14 coastal districts, focusing on sandy beaches in fishing-dominant villages. Thiruvarur district was excluded due to its mangrove-dominated shoreline, which is unsuitable for standard beach litter survey protocols. The Gulf of Mannar (GOM) region was also excluded from the beach litter survey to avoid duplication because the MARESSOL project had previously documented that Abandoned, Lost, or Discarded Fishing Gear (ALDFG) comprised nearly 50% of shoreline debris in that region.

KEY MESSAGES

The present baseline study highlights the prevalence and composition of beach litter, particularly ALDFG, which formed the largest proportion (47.46%) of all litter collected, followed by other plastics (39.64%) and non-plastics (12.9%). Based on surveyed litter concentrations, an estimated 1,61,450 ALDFG items weighing 6.47 tonnes were found across a total beach area of 3,63,300 m^2. Several informal solid waste dumping sites were also identified along the shore, often adjacent to the sea, posing a significant risk of land-based pollution entering marine environments, especially during monsoon periods. Fourier Transform Infrared Spectroscopy (FTIR) analysis identified polyethylene as the dominant polymer, underscoring persistent challenges in plastic waste management. The high proportion of polyamide in fishing nets and longlines reflects

the intensive fishing activities along the coast, where gear loss and improper disposal are key contributors to ALDFG accumulation

To estimate the annual ALDFG generation, structured interviews were conducted with fisherfolk using FAO's Global Fishing Gear Loss Assessment methodology. The interviews revealed the annual generation of 4,554 tonnes of ALDFG along Tamil Nadu's coastline. Common causes include snagging of gear on underwater obstructions, poor weather, gear entanglement, trawler damage, and lack of disposal facilities at fish landing centers.

To evaluate pollution severity, four Beach Quality Indices were applied. According to the Clean Coast Index (CCI), Villupuram district emerged as the most heavily littered area, while Pudukottai district was ranked the highest in plastic abundance and hazardous litter. Notably, 46% of surveyed beaches were categorized as "extremely dirty", and 62% showed extreme environmental degradation based on Clean Environment Index (CEI). The Plastic Abundance Index (PAI) scores indicated high densities of fishing gear-related plastic litter across districts, with rope, floats, and net fragments dominating. The Hazardous Litter Index (HLI) results further emphasized that 62% of beaches contained potentially hazardous litter.

To address beach litter pollution, the project recommended the establishment of Discarded Fishnet Collection Centres to facilitate the proper recovery and recycling of Abandoned, Lost, or Discarded Fishing Gear, a major contributor to shoreline debris. The first centre was launched at Kasimedu Fishing Harbour, with expansion planned across 13 additional coastal districts under the Tamil Nadu Fishnet Initiative (TNFI). This scale-up is aligned with the broader TN-SHORE (Tamil Nadu Sustainably Harnessing Ocean Resources and Blue Economy) project, which supports sustainable coastal development, ecosystem resilience, and improved livelihoods for fishing communities. Complementing these infrastructure efforts, community-based awareness programs were introduced to promote behavioural change and responsible fishing practices. Initially piloted in Kasimedu, these programs are being extended to other coastal districts, engaging key stakeholders including boat owners, fishnet vendors, fishers' associations, and school children to encourage proper gear disposal, recycling, and long-term environmental stewardship.

Although beach litter represents only one component of the broader marine litter challenge, it provides critical insight into pollution dynamics and serves as a gateway to evidence-based policy decisions. Integrating beach litter monitoring and management within larger marine litter control frameworks is therefore essential to achieve sustained reductions in coastal and marine pollution.


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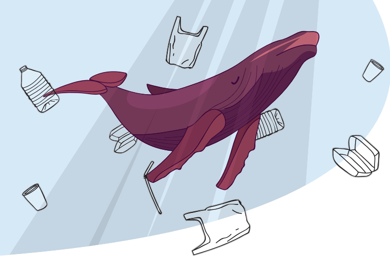
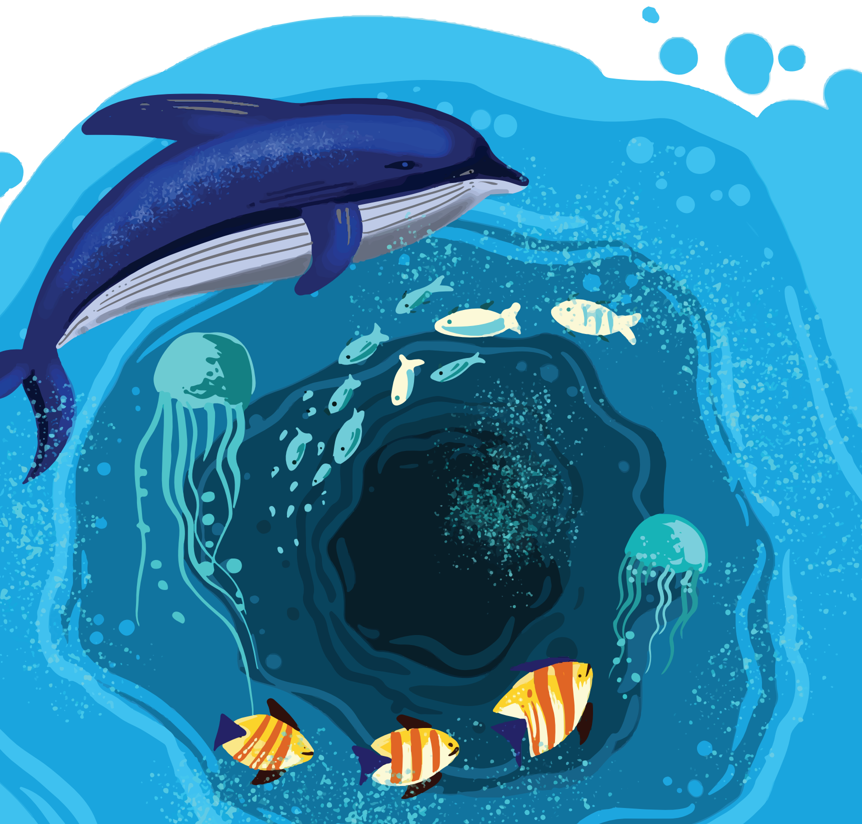


EXECUTIVE SUMMARY

Marine litter is a persistent and escalating global concern.It consists of solid manufactured/processed materials that enter and accumulate in the marine and coastal environments. It originates from both land-based sources including plastic waste mismanagement, industrial discharges, and tourism-related activities and sea-based sources such as commercial fishing, shipping, and aquaculture. This widespread pollution threatens marine ecosystems, biodiversity, coastal economies, and public health.

Depending on where it accumulates, marine litter is commonly categorized as floating litter (on the sea surface), benthic litter (on the seafloor), and beach litter (along the shoreline). Among them, beach litter is the most visible and easily measurable, becoming a useful indicator of wider marine pollution patterns.Influenced by a combination of tidal movements, wave action, wind transport and human activities, beach litter accumulates along shorelines degrading coastal habitats. Beach litter offers a practical entry point for understanding the composition and scale of marine debris.This study focuses on beach litter assessment as a key strategy for assessing shoreline pollution along Tamil Nadu's coastline. Due to its visibility and accessibility, beach litter provides a reliable, effective, and standard method for data collection, particularly for baseline assessments that inform local waste management and policy development.



This study assessed beach litter across 52 coastal villages in 13 of the 14 coastal districts of Tamil Nadu, India. Thiruvarur district was excluded due to its mangrove-dominated coastline lacking sandy or pebbled beaches, which is required for standardized shoreline surveys (NOAA methodology). The Gulf of Mannar was excluded, since comprehensive surveys under the MARESSOL project have already covered ALDFG patterns in that region. With a coastline of 1,068.69 km, Tamil Nadu hosts ecologically rich habitats such as coral reefs, seagrass meadows, and wetlands, but faces growing environmental and socio-economic challenges due to increasing beach litter accumulation.

The density and composition of beach litter at the selected sites were quantified using the National Oceanic and Atmospheric Administration (NOAA) marine debris assessment methodology, specifically the standing-stock survey approach. At each location, four 5-meter-wide transects were randomly placed along a 100-meter shoreline, covering 20% of the surveyed area. Litter was categorized according to the guidelines of the United Nations Environment Programme (UNEP) into three broad categories: plastics, non-plastics, and ALDFG. Additionally, polymer identification of plastic litter was performed using Attenuated Total Reflection-Fourier Transform Infrared Spectroscopy (ATR-FTIR) to determine material composition. This comprehensive assessment aims to provide baseline information to develop effective management strategies for mitigating beach litter pollution along Tamil Nadu's coastline.

A fisherfolk survey was conducted using the Food and Agriculture Organization (FAO) Global ALDFG Survey template to evaluate factors contributing to ALDFG generation. Between January and June 2024, a total of 470 fishers from the 52 coastal villages were interviewed using a structured questionnaire. The survey gathered data on fishing gear types, fleet size, fishing ground locations, and waste disposal practices, offering critical insights into gear loss and its contribution to beach litter pollution.

The study recorded 6,132 beach litter items weighing 201 kg along a surveyed shoreline of 1,040 meters, averaging approximately 5.9 items and 0.19 kg of litter per meter. ALDFG was the dominant litter type, accounting for 47.5% of the total debris count and 46% of the total weight.

Plastic debris comprised 39.64%, while non-plastic litter accounted for 12.9%. The highest litter density was observed in Pudukottai (2.68 items/m^2, 0.20 kg/m^2) and Villupuram (2.04 items/m^2, 0.09 kg/m^2). Fishing ropes (65.85%), floats and buoys (21.45%), and gillnets were the most prevalent ALDFG items, while plastic debris primarily consisted of bottle caps (25%), food wrappers (19%), and plastic bags (12%). Non-plastic litter was dominated by paper (29.3%), glass beverage bottles (28.6%), and clothing (23.03%).

Debris was categorized by size into three groups: meso (0.5-2.5 cm), macro (2.5-100 cm), and mega (greater than 100 cm). Among them, macro-sized debris contained the highest proportion of plastic at 20.5% and non-plastic litter at 11%. ALDFG was mainly found in the mega-sized category, comprising 28% of that group. Meso-sized debris, often buried beneath the sand and presenting a challenge to collection efforts, contributed to microplastic pollution. FTIR-ATR analysis identified polyethylene (27%) as the most common polymer, followed by polypropylene (20.39%), polyethylene terephthalate (PET) (9.48%), and polyamide (9.22%). Additionally, 10 solid waste dumping sites (ranging in area from 5 to 25 m^2) were identified, where domestic waste (59.27%), fishery by-catch waste (23%), and ALDFG (17.72%) were prevalent.

The accumulation of ALDFG in marine capture fisheries results from both intentional and unintentional factors, including fishing methods, adverse weather, accidental losses, inadequate disposal facilities, user conflicts, illegal fishing, ocean currents, and transboundary transport. Onshore net preparation and mending also contribute significantly to ALDFG, as plastic fragments from damaged nets and ropes are discarded. Additionally, land-based litter from urban runoff, industrial waste, and tourism significantly impacts beach pollution. Unregulated landfills, untreated municipal sewage, and inland waterways serve as pathways for plastic waste entering the marine ecosystem, exacerbating pollution in high-traffic tourist regions.

Beach litter accumulates through marine-based, land-based, and direct human inputs. Marine-based inputs, such as ALDFG, are transported by ocean currents, tides, and monsoonal winds. Land-based inputs, including waste transported by rivers, stormwater runoff, and urban discharges, also contribute significantly. Direct human activities such as tourism, coastal recreation, and fishing further accelerate litter accumulation. The prevalence of ALDFG and floating plastics along Tamil Nadu's coastline suggests transboundary movement of marine litter, complicating mitigation efforts. Seasonal weather patterns,

particularly the monsoons, significantly influence litter deposition, with storm surges and flooding increasing the accumulation of marine- and land-based debris.

The fisherfolk survey estimated that approximately 4,554 tons of ALDFG, with a 95% confidence interval (CI) ranging from 3,726 to 5,382 tons,are generated annually along Tamil Nadu's coastline. Gill nets and entangling nets contributed the highest loss of 2,004 tons (44%), with a CI of 1,728 to 2,280 tons, followed by surrounding nets contributing 1,417 tons (31%), with a CI of 1,121 to 1,714 tons, and seine nets 919 tons (20%), with a CI of 813 to 1,025 tons. Hooks and lines accounted for 214 kg (5%), with a CI of 64 to 363 tons. The survey also identified major factors contributing to fishing gear loss, including net snagging on underwater obstructions, poor weather conditions, gear entanglement, and displacement by trawlers. Additionally, a lack of disposal facilities at landing sites exacerbates ALDFG pollution. An overwhelming 94.81% of fishers expressed frustration over the unavailability of gear disposal facilities, and 90.81% predicted worsening gear loss incidents over the next five years without improved waste management systems.

Pollution intensity was assessed using four Beach Quality Indices (BQI): the Clean Coast Index (CCI), Clean Environment Index (CEI), Plastic Abundance Index (PAI), and Hazardous Litter Index (HLI). Villupuram recorded the highest CCI score, falling in the category of 'extremely dirty' due to heavy litter accumulation. Overall, 23% of beaches were 'moderately clean', 31% 'dirty', and 46% 'extremely dirty'. The highest CEI score was recorded in Pudukottai, highlighting severe environmental degradation due to high ALDFG density. The CEI analysis classified 62% of the area as "extremely dirty", 23% as "dirty", and only 15% as "moderate" in cleanliness. The PAI indicated that Pudukottai had the highest plastic debris concentration (20.6 items/m^2), primarily comprising fishing ropes, floats, buoys, and net fragments. Overall, 39% of surveyed beaches exhibited very high plastic abundance, 46% high abundance, and 15% moderate abundance. Regarding hazardous litter, Pudukottai had the highest HLI, with 62% of beaches exhibiting hazardous waste accumulation, while 38% of beaches were categorized as having considerable hazardous litter accumulation.

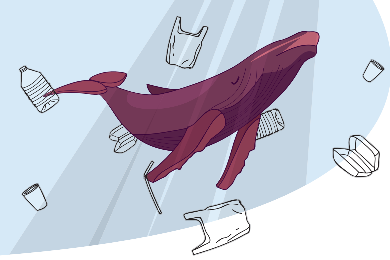
The findings emphasize that beach litter, particularly ALDFG, contributes significantly to coastal environmental degradation along Tamil Nadu's beaches. The prevalence of ALDFG, derived mainly from gill nets, entangling nets, seine nets, and fish traps, highlights the urgent need for

improved waste disposal systems for end-of-life fishing gear. This study also found that an estimated 4,554 tons of ALDFG are generated annually along Tamil Nadu's coastline, with gill nets and entangling nets contributing approximately 2,004 tons (44%), followed by surrounding nets (31%), seine nets (20%), and hooks & lines (5%). Without proper disposal facilities or collection points, these materials often accumulate along beaches, posing a severe threat to biodiversity, marine habitats, and coastal tourism.

Following the baseline survey, the Tamil Nadu Fishnet Initiative (TNFI) recognized that addressing ALDFG pollution required not just collection efforts but also a shift in stakeholder attitudes and practices. Awareness programs are essential in fostering long-term behavioural change, ensuring that fishers, recyclers, and coastal communities understand the environmental and economic consequences of ALDFG. By promoting responsible waste disposal and sustainable fishing practices, these programs help prevent the recurrence of ALDFG rather than relying solely on cleanup efforts. TNFI's awareness campaigns, initiated at Kasimedu Fishing Harbour, are expanding to coastal villages across Tamil Nadu. Key stakeholder engagement is central to this approach. Boat owners' associations are educated on responsible gear disposal, while fishnet shop operators are trained as collection hubs to streamline recycling. Fishermen welfare associations raise awareness of ALDFG's impact, and local trash collectors receive training on proper fishnet segregation. Additionally, educational programs for fishermen's children aim to instil long-term environmental responsibility.

A major milestone of TNFI is the establishment of Discarded Fishnet Collection Centres, with the first centre set up at Kasimedu Fishing Harbour based on baseline survey findings. Fishermen receive ₹40 per kg for discarded fishnets, as fair compensation. Between August 17, 2024 and January 31, 2025, the initiative collected 11,189 kg of discarded fishing nets, with ₹4,47,856 distributed as incentives to fishermen across 474 transactions, showcasing periodic surges in participation. Future plans include expanding collection centres and implementing digital monitoring system.

In conclusion, this study underscores the pressing need for targeted interventions to tackle ALDFG accumulation and promote sustainable fishing practices. A holistic approach combining regulatory enforcement, improved waste disposal infrastructure, and community-driven initiatives is essential to mitigating beach litter pollution. The integration of awareness programs, stakeholder engagement, and incentive-based collection systems has proven effective in fostering behavioural change and reducing the inflow of fisheries-related plastic waste. Strengthening these efforts and scaling up successful interventions will be critical in safeguarding Tamil Nadu's marine ecosystems and ensuring long-term sustainability in coastal resource management.



RECOMMENDED ACTIONABLE STEPS FOR ABANDONED, LOST OR DISCARDED FISHING GEAR (ALDFG) MANAGEMENT

Based on current gaps, international best practices, and regional needs, a phased action plan is proposed to guide the effective management of ALDFG in Tamil Nadu. Detailed recommendations are provided in Chapter 14. This section summarizes the key actionable steps for ALDFG management arranged into short-term, mid-term, and long-term timelines.

Short-Term (1-3 years)

Focus: Awareness, collection, enforcement, and stakeholder collaboration

- **School-based environmental education:** Collaborate with the National Council of Educational Research and Training (NCERT) and the Tamil Nadu School Education Department to integrate marine litter, ALDFG impacts, and sustainable fishing topics into school curricula. This will raise early environmental stewardship and awareness among students.

- **Multilingual media and mobile outreach:** Develop multilingual campaigns through community radio, local television, posters, and mobile apps to engage diverse coastal communities. These platforms can disseminate information on ALDFG hazards, best practices for gear disposal, and available reporting/recovery systems.

- **Community awareness:** Launch targeted awareness campaigns to educate fishers on the environmental and economic impacts of ALDFG.

- **Citizen-led monitoring:** Encourage citizen science groups and community members to participate in ALDFG hotspot mapping, gear retrieval reporting, and awareness efforts. Leveraging local knowledge and participatory tools can improve data accuracy and strengthen community engagement, and long-term stewardship.

- **ALDFG projects:** Implement more collection and recycling initiatives in high-priority fishing hubs, modelled on the Kasimedu fishnet collection centre.

- **Regulatory enforcement:** Strengthen enforcement of laws against illegal disposal of fishing gear to ensure compliance, especially in hotspot zones.

- **Incentive-based retrieval:** Introduce a verified buy-back or gear return scheme where fishers are rewarded for retrieving ALDFG, supported by Extended Producer Responsibility (EPR) contributions or government marine conservation budgets.

- **Data-linked incentive system:** A data-linked incentive system can be initiated using a mobile application to track recovered ALDFG, disbursed incentives, and recycling outcomes-ensuring transparency and enabling future expansion across coastal regions.

- **Multi-stakeholder task forces:** Form local ALDFG task forces involving fishers, harbour authorities, fisheries officials, NGOs, and scientists to coordinate retrieval, data collection, and community engagement.

- **Gender-inclusive participation:** Promote the engagement of fisherwomen in ALDFG collection, segregation, and recycling activities as part of livelihood empowerment under the blue economy framework. This promotes inclusive coastal development and acknowledges the valuable contributions of women in managing marine resources.

Mid-Term (3-5 years)

Focus: Infrastructure, livelihood creation, and sustainable technology adoption

- **Advanced technologies:** Upgrade ALDFG clean-up efforts using drone surveillance and AI-based tracking systems to locate and map ghost gear accumulation zones efficiently.

- **Recycling infrastructure:** Establish regional gear recycling centers in collaboration with the fishing industry and local authorities. These centers should process recovered gear into reusable materials or commercial products, encouraging circular economy practices.

- **Mobile collection units:** Deploy mobile ALDFG collection and sorting units in remote coastal villages. These units can support on-site segregation, temporary storage, and awareness campaigns.

- **Skills development and entrepreneurship:** Develop vocational training on gear repair and recycling to create local jobs.

- **Eco-friendly fishing gear:** Promote the transition to biodegradable and environmentally sustainable fishing gear by offering financial subsidies, technical training, and pilot demonstrations in partnership with fishing cooperatives and gear manufacturers.

- **Research and innovation support:** Encourage the state's institutions affiliated to Central Institute of Fisheries Technology (CIFT) and Indian Council of Agricultural Research (ICAR) to lead innovations related to sustainable fishing gear. Promote field trials of biodegradable fishnets and gear retrieval technologies (e.g., smart buoys), to support eco-friendly gear transitions and smart fishing practices.

- **Public-Private Partnerships (PPPs):** Promote partnerships between the government and private companies to set up and run gear recycling units, test biodegradable fishing gear, and support awareness programs. Involving the private sector can bring innovation, more funding, and help scale up long-term solutions for managing ALDFG effectively.

Long-Term (5-10 years)

Focus: Strategic integration and global alignment

- **Blue economy linkage:** Integrate ALDFG recovery into Tamil Nadu's broader blue economy strategy for inclusive and sustainable growth.

- **ALDFG Reduction targets:** Achieve a 50% reduction in ALDFG presence along Tamil Nadu's key coastal zones, using current baseline values derived from this assessment.

- **Circular economy integration:** Fully incorporate ALDFG into a state-wide circular economy, ensuring complete recovery and recycling of fishing gear.

- **Marine innovation hubs:** Establish marine innovation hubs for gear redesign, reuse, and circular fishing practices.

- **Global leadership:** Position Tamil Nadu as a regional and global leader in sustainable marine resource management by aligning ALDFG strategies with international conventions (like FAO Voluntary Guidelines, UNEA resolutions) and showcasing best practices through knowledge exchange platforms.

The integrated framework of short-, mid-, and long-term interventions for ALDFG management covers net waste collection, dedicated collection centres, gear recycling, financial incentives, awareness building, and cross-sectoral partnerships. Together, these actions aim to strengthen fisheries sustainability, improve environmental governance, and enhance the resilience of coastal economies.

1

BACKGROUND

1. BACKGROUND

Marine litter found accumulated along the coastline of Tamil Nadu, India, represents a growing environmental, ecological, and socio-economic crisis. With a coastline stretching to 1,068.69 km (MoPSW, 2025), Tamil Nadu is home to some of the most ecologically diverse marine habitats, including coral reefs, mangroves, seagrass beds, and estuaries. These ecosystems support a rich diversity of flora and fauna, contribute to the livelihoods of millions of people, and play a crucial role in regulating climate. However, the relentless accumulation of marine litter threatens these fragile environments as well as the communities dependent on them. The global accumulation of anthropogenic materials has now surpassed the total mass of living biomass on Earth (Elhacham et al., 2020). A major consequence of this unprecedented rise in human-made waste is its widespread dispersal into the natural world, with the oceans being the most affected (Jambeck et al., 2015). Over the past century, global waste generation has approximately doubled every two decades and is projected to reach 53 million tons per year by 2030, specifically for plastic waste (Borrelle et al., 2020). This growing tide of waste is driven by rapid population growth, urbanization, evolving consumption patterns, and changing lifestyles, all of which have strained waste management systems and led to the proliferation of waste in both land and marine environments.

Marine litter originates from a wide range of sources, both land-based, such as urban runoff and industrial activities, and sea-based, including fishing operations and maritime transport. These items can travel vast distances due to wind, water currents, and human activities before ultimately ending up in marine ecosystems (Özşeker et al., 2024). According to the National Oceanic and Atmospheric Administration (NOAA), billions of pounds of pollutants end up in our oceans each year, and the majority of it comes from human activities along the coastlines and inland (Lippiatt et al., 2013). The beach environment has been considered a sink for marine litter and studied intensively worldwide. This is because beaches represent the interface between land and sea and receive significant impact from human activities. Understanding the devastating effects of pollution on our beaches is the first step to fixing the problem. Beaches function as social-ecological systems where physical, ecological, social, and economic dimensions intersect and interact in complex ways. Robust beach ecosystems offer a range of essential services, including leisure and recreation, cultural heritage preservation, disturbance regulation, provision of habitats for animals and plants, nutrient cycling, and climate

regulation (Fig.1.1). These services substantially contribute to enhancing human well-being (Yu et al., 2022). Yet, as crucial coastal interfaces, beaches are increasingly vulnerable to a wide range of threats, both terrestrial and marine. Among them, plastic pollution has emerged as one of the toughest global environmental challenges, severely impacting the integrity of beach ecosystems (GESAMP, 2019). Consequently, it is imperative to investigate the distribution and accumulation of litter to inform sustainable coastal zone management practices.

In Tamil Nadu, the situation is no different, with the state's coastline being increasingly impacted by the growing influx of marine litter. Given the scope and severity of marine litter pollution, it is essential to assess the distribution, composition, and accumulation of waste on beaches to take effective coastal zone management measures. This research study undertook a comprehensive assessment of beach litter pollution in the Tamil Nadu coast in south-eastern India, focusing on the magnitude, sources, and composition of beach litter. The study involved systematic sampling and analysis of litter types, quantities, and their variations over different regions. Evaluation of both the physical and chemical properties of the beach litter helped generate insights into pollution sources and their implications for beach health and aesthetics. While simply measuring beach litter is not a solution in itself, the data gathered from this research will provide critical insights to guide decision-making and policy development. The findings will be instrumental in raising public awareness about the urgent need to address beach litter along the Tamil Nadu coastline. Moreover, they will contribute to the design of sustainable strategies for cleaner oceans, healthier beaches, and a more resilient coastal environment.

Fig. 1.1: Key functions and services of the beach ecosystem

1.1. Marine litter pollution: an overview

Marine litter is an urgent and escalating global issue, characterized by a wide range of materials that end up in the oceans, either directly or indirectly. This problem poses significant environmental, health, economic, and aesthetic threats to the planet. Marine litter is particularly insidious because it often takes a long time to degrade, resulting in a continuous accumulation of harmful waste in marine and coastal ecosystems (Lincoln et al., 2022). Its persistence in the environment, coupled with the ongoing introduction of new litter, demands immediate and coordinated action at local, regional, and global levels. The sources of marine litter are varied and complex, arising from both land-based and sea-based

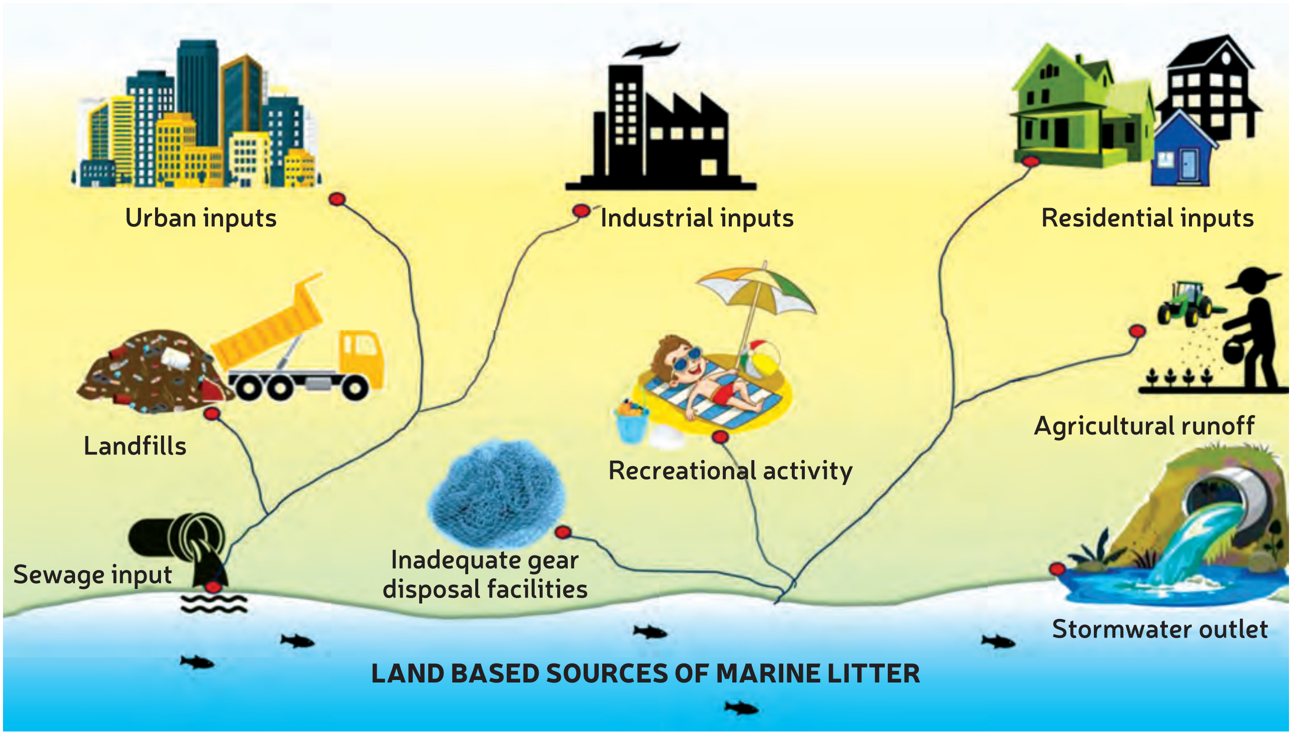


Fig. 1.2: Land-based sources contributing to marine litter pollution

human activities. Land-based sources include urban runoff, improper waste disposal, industrial discharge, and agricultural runoff (Fig.1.2). Activities such as tourism, beach outings, and recreational boating, along with inadequate waste management practices in cities and villages, all contribute to the pollution of oceans (Bekova & Prodanov, 2024). Sea-based sources, such as fishing, shipping, and offshore oil platforms, are also significant contributors (Fig.1.3). Additionally, rivers and coastal waters act as conduits, transporting litter from inland areas to the sea (Prevenios et al., 2017).

Every day, a significant amount of waste, including plastics, metals, rubber, textiles, abandoned fishing gear, and derelict vessels, enters the marine environment. This influx of materials leads to devastating impacts on marine ecosystems, human livelihoods, and coastal economies. The most insidious component of marine litter is plastic, which accounts for over 80% of the debris found on beaches, floating on the surface of the ocean, or accumulating on the seabed (Martín-Lara, 2021). Plastics persist in the environment for centuries, slowly breaking down into smaller particles called microplastics (MPs; size <5 mm), which, even in their smallest forms, continue to harm marine life. The slow degradation of many types of marine litter means that the problem is cumulative, with more and more debris accumulating over time. According to one estimate, between 4.8 and 12.7 million tons of waste enter the oceans each year (Tubau et al., 2015). These materials can float on the surface, get trapped in the water column, or sink to the ocean floor, where they can remain for long periods. As they drift, plastics accumulate persistent organic pollutants (POPs) and invasive species, which are then carried across ocean currents to new and sometimes remote regions, further exacerbating the ecological damage (Kingsolver, 2022).

The environmental impacts of marine litter are profound. Marine animals such as birds, mammals, turtles, and fish are highly susceptible to the dangers of plastic pollution. Ingestion of

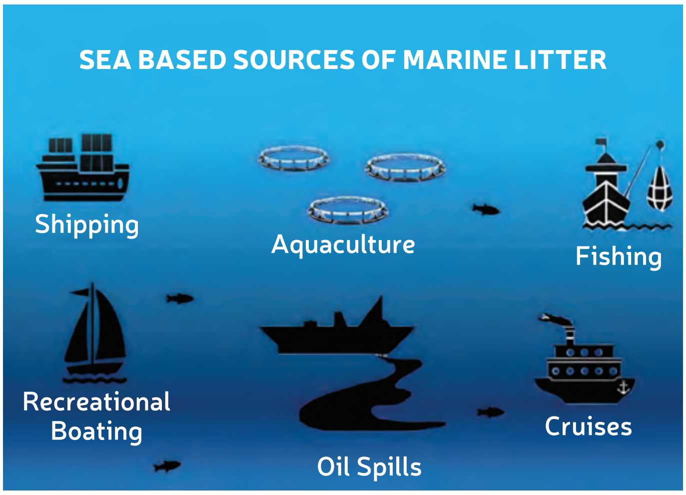


Fig.1.3: Sea-based sources contributing to marine litter pollution

plastic debris, entanglement in discarded fishing nets (ghost gear), and suffocation or injury caused by litter are just a few of the risks posed to wildlife. It is estimated that over 267 species worldwide are affected by marine litter, with 86% of turtle species, 44% of birds, and 43% of marine mammals suffering from the consequences (EPA, 2021). The ingestion of plastics by marine animals can lead to starvation, injury, and death, while entanglement can cause suffocation and long-term suffering. Marine litter also poses significant health risks to humans. The presence of hazardous materials such as medical waste, syringes, and chemicals in marine litter can lead to direct health hazards, particularly to coastal communities and workers involved in fishing or beach clean-up activities (Williams and Rangel-Buitrago, 2022). In addition, plastics and other debris contribute to the spread of harmful pathogens, which can enter the human food chain through seafood consumption. The contamination of the marine food web, from plankton to apex predators, is one of the long-term effects of plastic pollution in the oceans, causing enormous concern. The economic impact of marine litter is also considerable. Coastal tourism, a significant source of income for many countries, is adversely affected by the presence of debris on beaches. Tourists are less likely to visit polluted beaches, leading to a loss of revenue and job opportunities. In addition, industries such as fisheries and aquaculture suffer from the costs associated with marine litter, including damage to fishing equipment, reduced fish stocks, and increased cleaning and disposal costs (UN Environment, 2017). Furthermore, local governments spend millions of dollars annually on beach clean-up and waste management efforts, which could more effectively be directed toward sustainable waste management practices.

Marine plastics, in particular, have been identified as "threat multipliers" because their presence compounds the effects of other environmental stressors, such as climate change. Plastics derived from fossil fuels release greenhouse gases throughout their life cycle, from production to disposal, contributing to global warming (Ford et al., 2022). Additionally, the degradation of plastics in the ocean releases harmful chemicals, further degrading the marine environment and impacting biodiversity. Once marine debris enters the ocean, it can be transported over vast distances, crossing entire ocean basins. This dispersal is driven by key environmental forces such as ocean currents, river inputs, wind, and rainfall, which collectively influence the movement and accumulation of plastic debris across different marine zones (Fig.1.4). Over time, the debris becomes increasingly fouled by microorganisms

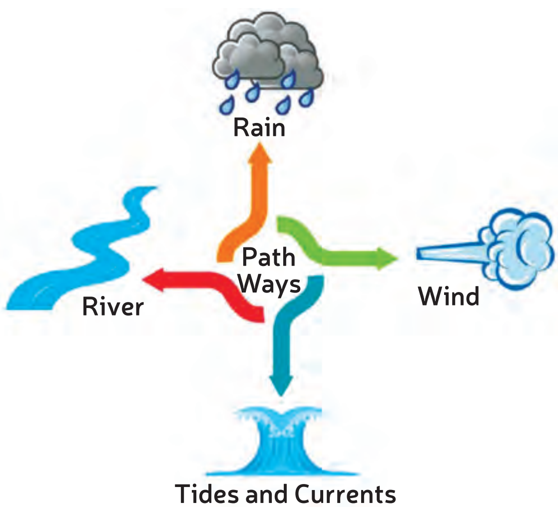


Fig.1.4: Key drivers of marine debris dispersal: ocean currents, river inputs, wind, and rain influence

and aquatic life, gains weight, and eventually sinks to the seafloor, where it can persist for centuries. Benthic organisms, which rely on clean and stable environments, are particularly vulnerable to the accumulation of debris on the ocean floor. The presence of marine litter disrupts essential ecosystem services, such as nutrient cycling and habitat formation, and can alter the composition of species in these ecosystems (Saldanha et al., 2003).

Despite these challenges, efforts to address marine litter have gained significant momentum in recent years. International agreements, such as the United Nations Sustainable Development Goal 14 (2015), aim to conserve and sustainably use the oceans, seas, and marine resources. Regional conventions like the European Marine Strategy Framework Directive (2008) and the UNEP Regional Seas Programme have played critical roles in fostering cooperation and developing strategies for marine litter management. The severity of the beach litter crisis calls for immediate, coordinated action at the global, national, and local levels. The amount of litter in our seas and on our beaches is primarily influenced by two main factors: the rate at which litter is introduced into these environments and the effectiveness of its removal or the breakdown process. Monitoring trends and identifying changes in litter levels across various areas requires a systematic approach to tracking marine litter (Carvalho et al., 2021). Notably, the sight of litter along coastlines not only has negative impacts but also brings attention to coastal ecosystems and emphasizes the need for immediate action to address this pollution problem (Lucrezi and Digun-Aweto, 2020). Furthermore, reducing beach litter is crucial to decreasing overall marine litter pollution, as a considerable amount of ocean debris originates from items that are washed off beaches into the water. Effective solutions must include better waste management, stricter regulations, public education, and increased funding for research and innovation. Systematic monitoring of litter, through citizen science and government initiatives, is crucial to understanding the scale and trends of the problem. Additionally, fostering collaboration among governments, the private sector, NGOs, and the general public is essential for achieving lasting change (Patra et al., 2023). This book aims to provide an in-depth examination of the status, sources, impacts, and management strategies of beach litter pollution along the Tamil Nadu coast, one of India's most important and vulnerable coastal regions (Saxena et al., 2013). By exploring regional challenges and global trends, this work seeks to contribute valuable insights into the development of effective, sustainable strategies for combating marine litter pollution and protecting the health of our oceans for future generations.

1.2. Historical context and global relevance

Humans generate substantial amounts of solid waste daily, with a significant portion consisting of plastic materials. The widespread use of single-use plastics, designed for convenience but ultimately intended for disposal, is a major contributor to the growing problem of pollution, particularly in marine environments. The accumulation of plastic waste in our oceans has reached alarming proportions, with enormous quantities of plastic littering marine ecosystems (Jambeck et al., 2015).

Evolving through continuous innovations and becoming one of the most versatile and widely used materials in modern civilization, plastic has a history of over 150 years. Today, plastic plays an integral role in various industries, including packaging, construction, and healthcare. However, the roots of plastic-like materials extend much further, long before the Industrial Revolution, with ancient civilizations using natural substances exhibiting plastic properties. For example, materials such as rubber, amber, horn, and tortoiseshell were used to craft tools and decorative objects, demonstrating early human ingenuity in utilizing resources with plastic-like qualities. One of the earliest known plastics is believed to be latex, used by indigenous cultures in South America over 1,600 years ago (Moshood et al., 2021). This early adoption of plastic materials set the stage for a long history of experimentation with synthetic polymers, leading to the modern era of plastic production.

1.2.1. The development of modern plastics

In 1869, John Wesley Hyatt invented the first synthetic polymer, creating a material that could imitate natural substances such as tortoiseshell and ivory. This breakthrough was hailed as both an environmental and economic solution, as it was marketed as a substitute for natural resources that were in limited supply. In 1907, Leo Baekeland invented Bakelite, the first fully synthetic plastic, which was durable, heat-resistant, and ideal for mass production. The success of Bakelite spurred further investment in the development of new plastics, leading to an explosion in the production and use of plastic materials (Chalmin, 2019) (Fig. 1.5).

The urgency of plastic production reached new heights during World War II, when the need for synthetic materials led to a 300% increase in plastic production in the United States. Innovations like nylon and Plexiglas played pivotal roles during the war and became central to post-war industries. This accelerated growth continued

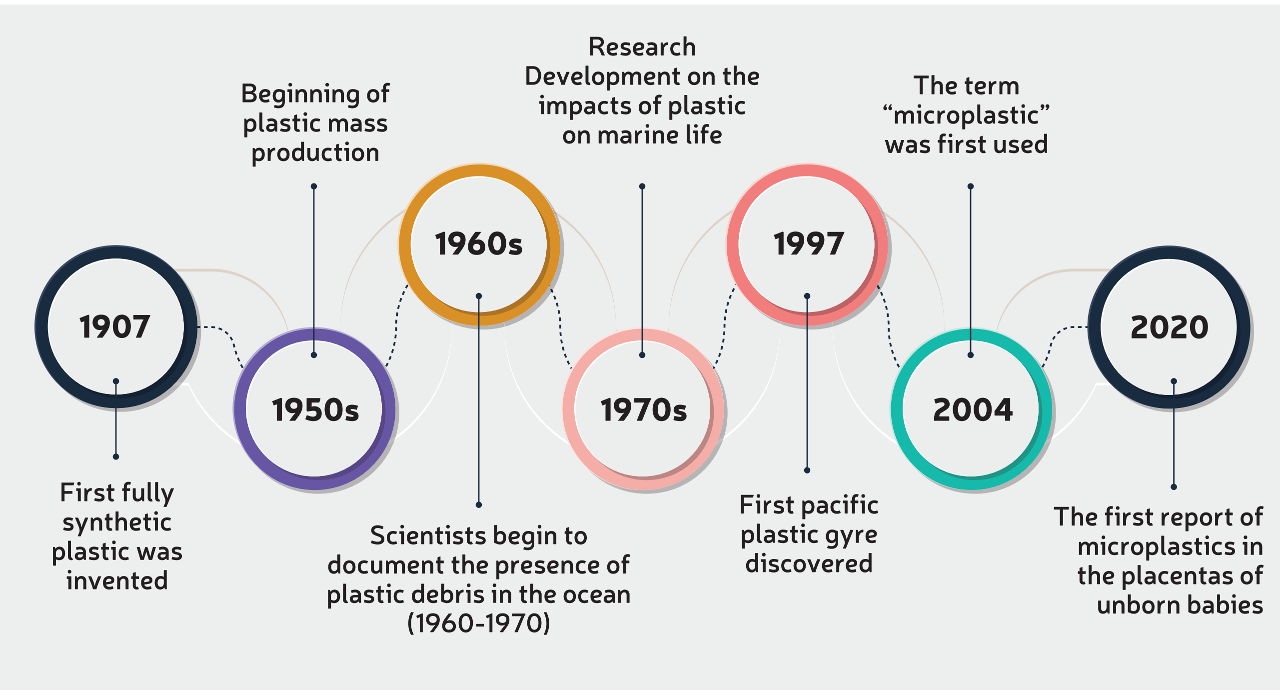


Fig.1.5: Timeline summarizing important events in the development of plastics

throughout the 20th century, with annual plastic production rising from 2 million tons in 1950 to 380 million tons in 2015 (Geyer et al., 2017). Production rates are projected to increase by another 40% in the coming decade, exacerbating the global plastic waste problem.

1.2.2. Growing concerns in marine environments

As the plastic industry flourished, the concerns about its environmental impacts heightened. The 1960s marked a critical shift in awareness regarding plastic pollution, particularly in the oceans. Early signs of plastic debris in marine environments were noted in the mid-20th century, with the Continuous Plankton Recorder (CPR) being used to sample plankton as indicators of ocean health. In 1957, the first instance of marine litter, specifically fishing line, was recorded off the coast of Iceland, marking the beginning of documented plastic pollution in the oceans. By 1965, a plastic bag was found entangled off the coast of Ireland, signalling the growing prevalence of plastic waste in marine ecosystems (Abalansa et al., 2021).

By the late 1950s and early 1960s, researchers began to observe the harmful effects of plastic pollution on marine life. Notable early reports include cases of marine turtles ingesting plastic bags, which often led to fatalities (Cornelius, 1975; Balazs, 1985).

Studies also documented the ingestion of plastics by Laysan Albatrosses (Kenyon and Kridler, 1969) and Atlantic puffins (Parslow & Jefferies, 1972), highlighting the growing threat to marine fauna from plastic waste. In the 1970s, the first substantial evidence of plastic fragments in marine environments was collected. These included plastic pellets (2.5-5 mm) found on the surface of the Sargasso Sea and in the coastal waters of southern New England (Carpenter et al., 1972b; Colton et al., 1974). This period also saw the identification of plastic as a major contributor to marine litter, with studies showing that plastics lingered far longer on beaches than glass bottles (Dixon and Cooke, 1977).

1.2.3. Global expansion of plastic pollution

The severity of the problem continued to grow throughout the 1980s and 1990s, as plastic debris accumulated in vast quantities across the globe. In 1980, a significant increase in plastic litter was reported on Alaskan beaches, primarily from fishing activities. This observation was followed by reports of plastic found in the stomachs of marine animals, further underscoring the dual crisis of toxicity and physical harm caused by plastic waste (Connors and Smith, 1982; van Franeker, 1985). A breakthrough moment in the history of marine plastic pollution came in 1997 when Captain Charles Moore discovered the "Great Pacific Garbage Patch", a massive accumulation of plastic debris floating in the North Pacific Subtropical Gyre (Moore et al., 2001). This discovery brought global attention to the scale of plastic pollution, with the Great Pacific Garbage Patch serving as a symbol of the ongoing environmental crisis.

1.2.4. The emergence of microplastics

As plastic waste continued to accumulate, a new phenomenon emerged: microplastics. Thompson et al. (2004) coined the term "microplastics" to describe small plastic particles, typically smaller than 5 mm that were becoming widespread in marine environments. Research in the ensuing years confirmed that microplastics were present not only in the water column but also in sediments, beaches, and marine animals. The presence of microplastics in the food chain, particularly in shellfish and other seafood, raised concerns about potential human exposure (Rahmatin et al., 2023). By 2009, researchers had

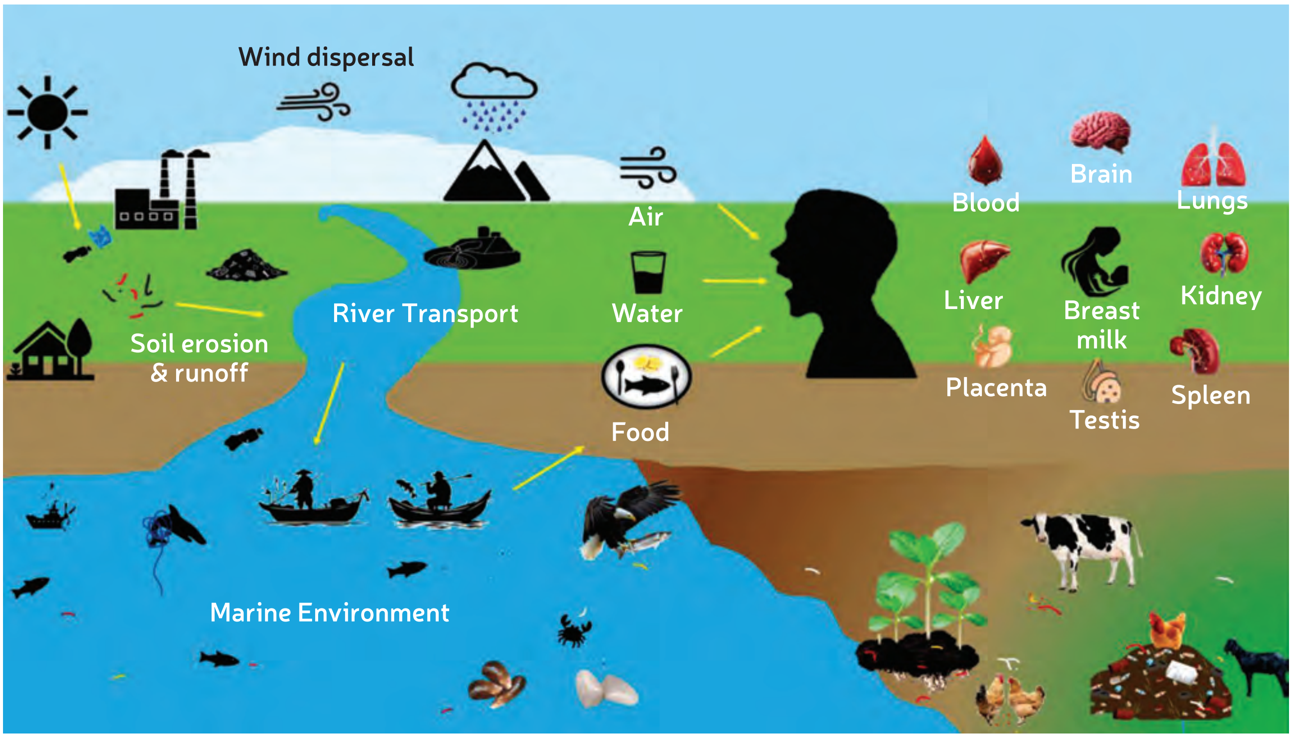


Fig.1.6: Microplastics everywhere: from oceans to human bodies

refined the definition of microplastics, and the scientific community began to pay greater attention to their impact on marine ecosystems and human health.

The growing presence of microplastics across the globe has made them a focal point in environmental studies. These tiny particles are found in coastal waters, remote islands, and even the deep sea (Ivar do Sul et al., 2009; Desforges et al., 2014). Microplastics are not only causing harm to marine organisms but are also being detected in food products, including seafood, salt, milk, tea, honey, bottled water, fruits and vegetables, posing potential risks to human health (Jayavel et al., 2024) (Fig.1.6).

1.2.5. Global relevance of marine litter pollution

Today, marine litter, especially plastics and microplastics, represents one of the most pressing environmental challenges globally. Plastic pollution is ubiquitous in oceans, affecting not only marine biodiversity but also human health, coastal economies, and tourism industries. Microplastics have been detected in nearly every part of the human body, including breast milk, blood, and organs (Wright and Kelly, 2017), highlighting the growing concern over the long-term health implications of this pollution. The global reach of marine litter is a testament to the pervasive nature of plastic waste, with plastics found on shorelines, deep-sea habitats, and remote islands far from human activity (Thushari & Senevirathna, 2020). Additionally, the fact that plastics persist in the environment for hundreds of years means that future generations will bear the consequences of the plastic waste accumulated today. The urgency of addressing marine litter pollution is more critical than ever.

Marine litter significantly impacts the economy by negatively affecting industries heavily reliant on healthy marine environments, primarily tourism and fisheries, through reduced visitor numbers due to unsightly beaches, damage to fishing gear, and decreased fish populations, ultimately leading to loss of revenue and jobs for

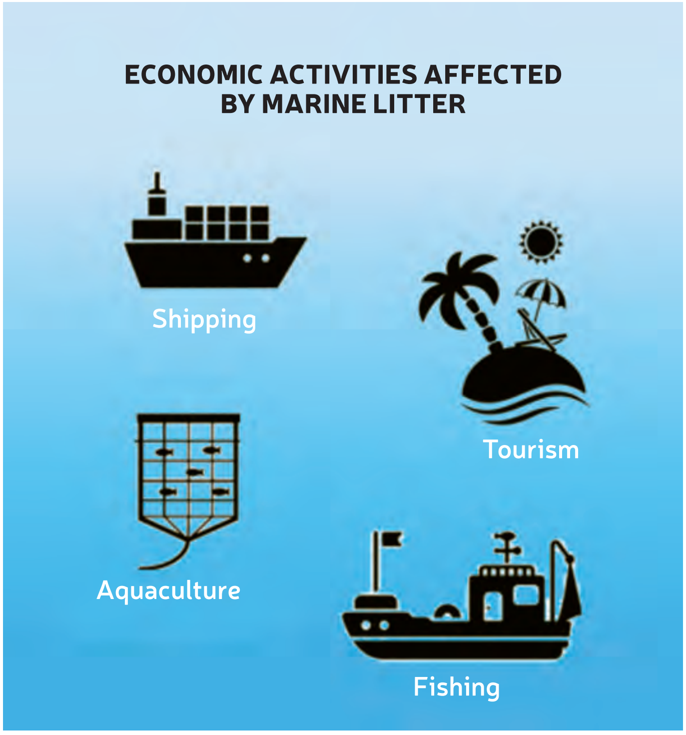


Fig.1.7: Economic impacts of marine litter: effects on shipping, tourism, aquaculture, and fishing

coastal communities; additionally, the clean-up costs associated with removing marine debris further burden the economy. It is not just an environmental issue; it is an issue that touches on human health, climate change, and sustainability (Dwivedi et al., 2022). As awareness grows and research advances, it becomes clear that concerted global action is required to combat this persistent threat to our oceans and the life they support (Fig.1.7).

1.2.6. Towards solutions: global efforts and policy shifts

The scale of plastic pollution has sparked international efforts to mitigate its impact. In recent years, significant global initiatives have been introduced to reduce plastic waste, such as the United Nations Clean Seas campaign, which aims to reduce plastic waste in marine environments. Additionally, the European Union's Single-Use Plastics Directive, which aims to curb the use of single-use plastics by 2021, is a major step toward reducing plastic pollution. Countries around the world have begun adopting stricter regulations on plastic production, consumption, and disposal, including bans on plastic bags, straws, and other disposable plastic items. Innovations in biodegradable plastics and more sustainable alternatives are also being explored, while recycling technologies are improving to reduce the amount of plastic waste that ends up in landfills or the oceans (Stoett et al., 2024). However, the effectiveness of these policies and technologies remains contingent on global cooperation and collective action.

The upcoming Global Plastic Treaty, currently being negotiated under the mandate of the United Nations Environment Assembly (UNEA), represents a landmark international effort to address the full life cycle of plastic pollution from production and design to disposal and remediation. Slated for finalization by 2025, the treaty aims to create a legally binding framework that tackles not just marine litter but also the broader environmental, health, and socio-economic impacts of plastics. With participation from over 175 nations, the treaty underscores a global consensus on the urgent need for coordinated action to curb plastic pollution, promote circular economy principles, and ensure equitable responsibilities and support for developing countries. If effectively designed and implemented, the treaty holds the potential to transform global plastic governance and set ambitious, science-based targets for a sustainable, plastic-resilient future.

2

MARINE LITTER

2. MARINE LITTER

2.1. Definition and characteristics

Marine litter refers to items of anthropogenic origin that become litter when they enter the environment. According to the United Nations Environment Programme (UNEP), marine litter is defined as "any persistent, manufactured, or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment." It includes all anthropogenic material introduced into the marine environment through intentional or unintentional human actions (Bettencourt et al., 2021)(Fig.2.1).

Marine litter consists of a wide range of materials, including glass, metal, plastics, ceramics, rubber, paper, textiles and processed wood. For example, glass bottles, aluminium cans, plastic packaging, ceramic tiles, rubber tires, paper cartons, and wooden crates are common types of litter found in marine environments. It can be found across all marine habitats, from densely populated urban coastlines to remote regions far from human activity (UNEP, 2009). Marine litter is present in diverse environments, from beaches and shallow waters to the depths of ocean trenches (Miyake et al., 2011).

The density and distribution of marine debris vary significantly, influenced by factors such as:

- Intensity of anthropogenic activities
- Hydrological and meteorological conditions
- Geomorphology
- Entry points of debris
- Physical characteristics of the debris

Currently, there is a substantial gap in the quantitative knowledge about the sources and input loads of marine litter, as well as the specific sectors and demographics involved in its production. Recent studies, such as those conducted by the Ocean Conservancy, have begun to quantify the scale of litter inputs, identifying coastal cities and river systems as significant contributors to marine pollution (Sivadas et al., 2022).

Marine littering is a significant environmental issue that highlights systemic challenges in waste management and consumer behaviour. These challenges include inefficiencies in recycling infrastructure, lack of global policies on plastic reduction, and cultural attitudes toward disposable products (Rossi et al., 2023). Addressing this issue requires an in-depth analysis of several critical factors:

1. **Key locations of litter release:** Identifying areas such as urban cities, rural regions, and coastal zones where littering is most prevalent.
2. **Behavioural and industrial contributions:** Understanding the characteristics and actions of individuals and activities responsible for littering, including tourists, fishing practices, residents, and various industries.
3. **Reasons for littering:** Investigating factors such as lack of awareness, convenience, and inadequate waste disposal facilities.
4. **Pathways to the marine environment:** Mapping the routes through which litter enters the marine environment, such as river runoff, storm drains, and beach pollution.

By addressing these factors, we can develop targeted action plans and policies to combat marine litter effectively.

Fig.2.1: Understanding marine litter: sources, types, and environmental impact

2.2. Classification of marine litter

Marine litter can be classified based on material type, source, and usage, which aids in identifying pollution origins and designing effective mitigation strategies. According to the National Oceanic and Atmospheric Administration (NOAA), marine debris is broadly categorized into plastic, glass, metal, rubber, cloth, wood/paper, and other materials. These items are further grouped by usage into consumer-related debris (bottles, bags, food wrappers), industrial-related debris (pellets, strapping bands), and Abandoned, Lost, or Discarded Fishing Gear (ALDFG) originating from maritime activities. Classification also considers whether the source is land-based (urban runoff, tourism, mismanaged waste) or ocean-based (shipping, fishing, aquaculture). This structured categorization provides valuable insights into the sources, transport pathways, and potential environmental impacts of marine litter, facilitating more targeted and informed interventions (NOAA, 2020).

Marine litter is also commonly categorized according to where it accumulates within the marine environment (UNEP/IOC (2009). This includes:

- **Floating litter,** which remains buoyant on the sea surface and is often transported over long distances by currents and winds
- **Benthic litter,** which sinks and settles on the seafloor
- **Beach litter,** which accumulates along the shoreline due to tidal action, wave energy, wind, and human activity.

Beach litter, in particular, is the most visible and accessible form, becoming a valuable proxy for assessing broader marine pollution trends.

2.2.1. Plastics

Plastics represent one of the most persistent and challenging types of marine debris. This category includes a wide range of synthetic materials used in products like food- and beverage packaging, plastic bags, electronic products, medical devices, car components, and household appliances. During production, various chemicals are added to the plastic to impart specific properties such as flexibility, vibrant colours, and resistance to sunlight or heat. These additives contribute to the complexity of plastics and make their decomposition difficult. While plastics can fragment into smaller pieces, known as microplastics, they may never completely degrade. This slow decomposition increases the likelihood of harmful interactions with marine organisms, as plastics can persist in the environment for centuries (Seyyedi et al., 2023).

2.2.2. Aluminum cans

Despite their recyclability, a substantial number of aluminium cans end up in marine ecosystems. These cans can take around 200 years to fully decompose, during which they can release harmful substances into the water and pose risks to marine life. Encouraging proper recycling practices can significantly reduce their environmental impact (Mrozik et al., 2021).

2.2.3. Glass bottles

Glass bottles are among the most enduring forms of marine debris, with an estimated decomposition time of approximately 1 million years. Their durability allows them to persist in the ocean for centuries, often breaking into smaller, sharp fragments that pose hazards to marine life. Although glass is recyclable, improper disposal frequently leads to its accumulation in aquatic environments (Barnes et al., 2009).

2.2.4. Processed timber

Processed timber, such as wooden pallets and crates, can decompose relatively quickly in marine environments compared to other materials. Marine organisms like shipworms (Teredinidae) play a significant role in accelerating the decay process by boring into the wood. Depending on the type of wood and environmental conditions, a large portion of its mass can be lost within the first few months (Charles et al., 2016).

2.2.5. Paper products

Paper products decompose much faster in marine environments than materials like aluminium or glass. Depending on factors such as thickness and the presence of coatings or additives, paper can break down within two weeks to two months. However, even short-lived paper debris can pose risks to marine wildlife, including ingestion or entanglement (Dimassi et al., 2023).

2.2.6. Rubber

Rubber's decomposition rate varies widely depending on its composition and environmental conditions. For example, rubber boot soles can take 50-80 years to break down significantly, while other types of rubber may persist for much longer. Encouraging the use of biodegradable alternatives can help mitigate this issue (Markovičová and Zatkalíková, 2024).

2.2.7. Clothing and textiles

The decomposition of textiles in the ocean depends on the type of fabric and environmental factors. Natural fibers, such as cotton, degrade relatively quickly, taking 2 to 5 months to break down (Fig.2.2). In contrast, synthetic fibers like polyester can remain intact for over 200 days, and some synthetic textiles exhibit no signs of degradation even after more than a year submerged in seawater (Royer et al., 2021). These findings highlight the importance of addressing the impact of synthetic clothing and promoting sustainable materials.

2.2.8. Implications for marine life

The persistence of marine debris has profound implications for marine ecosystems. Long-lasting materials, such as plastics and glass, pose enduring threats to marine organisms through ingestion, entanglement, and habitat degradation. Understanding the decomposition rates and environmental impact of different types of marine debris is crucial for developing effective waste management strategies and reducing pollution in our oceans (Dimassi et al., 2023).

2.3. Sources of marine litter

Marine litter originates from diverse sources, which can be classified using the attribution-by-litter-type method (Tudor and Williams, 2004). This method divides sources into four categories:

Fig.2.2: Decomposition rates for marine debris

1. Land-based sources: These sources account for the majority of marine litter and include activities such as recreational use of beaches, improper waste disposal by the public, industrial discharges, and sewage-related debris. Litter from land-based sources often reaches marine environments through rivers, stormwater runoff, industrial effluents, or winds (Lebreton et al., 2017). Examples include plastic bags, food wrappers, and sewage-related items like sanitary products.

2. Sea-originated sources: This category refers to debris generated from maritime activities, including commercial shipping, fishing, aquaculture, and offshore industries like oil and gas platforms. Typical items include fishing nets, buoys, ropes, traps, and oil drums. Such debris often drifts ashore due to ocean

currents and winds, highlighting the need for better waste management in marine industries (Deville et al., 2023).

3. Transboundary sources: Transboundary marine litter is debris transported across borders by ocean currents and winds. Items originating from neighbouring countries can often be identified by unique features such as manufacturing labels, barcodes, or telephone numbers. These items demonstrate the interconnected nature of marine pollution and underscore the need for international collaboration (Krelling et al., 2017).

4. Uncertain Sources: Litter that lacks identifiable markers or features falls under this category. These items could originate from either land or sea, making their exact source difficult to be determined (Galgani et al., 2015).

Once in the marine environment, litter can accumulate in various locations (Galgani et al., 2015):

- **Shorelines:** Debris deposited by wave action, tides, and wind, frequently surveyed through beach litter monitoring protocols (UNEP/IOC, 2009)
- **Water Surface:** Floating litter composed mostly of low-density plastics observed via aerial, ship-based, and drone surveys (Topouzelis et al., 2021)
- **Water Column:** Items suspended within the water, influenced by currents and density, studied using net tows and in-situ water sampling (Cózar et al., 2014)
- **Seafloor:** Heavier, non-buoyant materials such as fishing gear and dense plastic types, commonly identified through trawl surveys, remotely operated vehicles (ROVs), and scuba diving in benthic environments (Pham et al., 2014)

A significant portion of plastic litter sinks over time due to biofilm formation by microorganisms or sediment accumulation, rendering much of it invisible to the human eye. These biofilms, often composed of diverse microbial communities, form what is known as the plastisphere—a unique ecological niche that develops on the surface of plastic debris in aquatic environments (Zettler et al., 2013). The plastisphere not only accelerates the sinking of plastics through microbial colonization and increased weight but also introduces new ecological dynamics, including the transport of invasive species and potentially harmful pathogens.

This hidden litter poses significant threats to benthic ecosystems (Moyal et al., 2023). However, shoreline surveys, particularly of beaches, play a pivotal role in understanding the dynamics of marine litter. Beaches serve as critical monitoring sites for assessing the accumulation, distribution, and composition of debris (Haseler et al., 2020). Since this report focuses on beach litter surveys, particular emphasis is placed on systematic data collection from shorelines, which provides valuable insights into the interaction between land-based and marine-based sources of litter. Shoreline studies also highlight the importance of localized solutions tailored to specific regions, such as Tamil Nadu, where beach ecosystems are essential for community livelihoods and biodiversity.

3

MARINE LITTER FROM FISHERIES

3. MARINE LITTER FROM FISHERIES

Marine litter is one of the most pervasive and challenging environmental issues affecting the world's oceans. Among its various sources, marine litter from fisheries constitutes a significant portion, with abandoned, lost, or discarded fishing gear (ALDFG) emerging as a critical contributor. Fishing operations, both industrial and artisanal, rely heavily on durable synthetic materials for their gear, but when improperly managed, these materials persist in the marine environment, causing widespread ecological, economic, and social impacts (UNEP, 2016). The introduction of synthetic polymers in the mid-20th century revolutionized the fishing industry, enabling the production of strong, lightweight, and cost-effective gear. However, this innovation also contributed to an unintended consequence: the accumulation of fishing gear in the oceans, where it can persist for decades due to its resistance to degradation (Rangel-Buitrago et al., 2022).

Today, fishing-related litter is recognized as a primary source of macroplastics in marine ecosystems (Löhr et al., 2017). Marine litter from fisheries affects marine biodiversity and ecosystem services, disrupts economic activities such as fisheries and tourism, and poses risks to human health and safety. Ghost fishing, habitat destruction, and the generation of microplastics are among the most significant ecological consequences. Economically, the loss of fishing gear reduces fishery yields, increases operational costs, and burdens governments and communities with expensive clean-up operations. Socially, marine litter from fisheries compromises the livelihoods of coastal communities and undermines the aesthetic value of coastal and marine environments (Beaumont et al., 2019). Addressing this issue requires a comprehensive under-

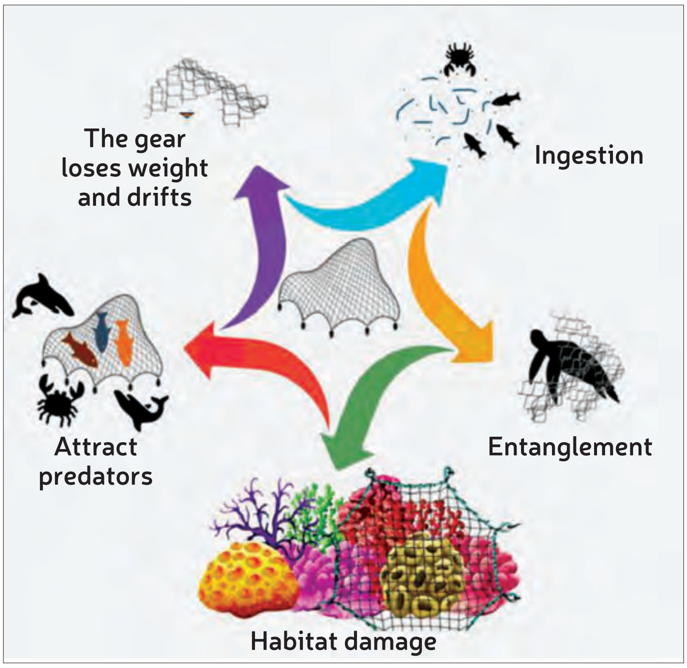


Fig.3.1: Ecological consequences of marine litter

standing of its sources, impacts, and potential solutions. This chapter delves into the problem of marine litter from fisheries, focusing on ALDFG and its far-reaching consequences. It examines the ecological, economic, and social dimensions of the issue (Fig.3.1).

3.1 Abandoned, Lost, or Discarded Fishing Gear (ALDFG)

ALDFG is one of the most concern-causing contributors to marine litter, posing significant ecological, economic, and social threats. ALDFG primarily includes fishing nets, ropes, traps, hooks, buoys, and other equipment that end up in the marine environment due to accidental loss, operational challenges, or deliberate disposal (Gilman et al., 2016) (Fig.3.2). These materials are typically made of synthetic polymers such as nylon, polypropylene, and polyethylene, which are designed for durability but remain in marine ecosystems for decades, causing prolonged damage (Link et al., 2018).

The scale of the problem is alarming. The FAO and UNEP (2009) estimate that globally, 640,000 tons of fishing gear are abandoned or lost every year, accounting for approximately 10% of total marine debris and up to 70% of macroplastics by weight in some oceanic regions. Factors driving this phenomenon include severe weather events, gear entanglement on seabed structures, conflicts in crowded fishing zones, and insufficient waste reception facilities in ports. Additionally, the high cost of retrieval and inadequate reporting of lost gear exacerbate the

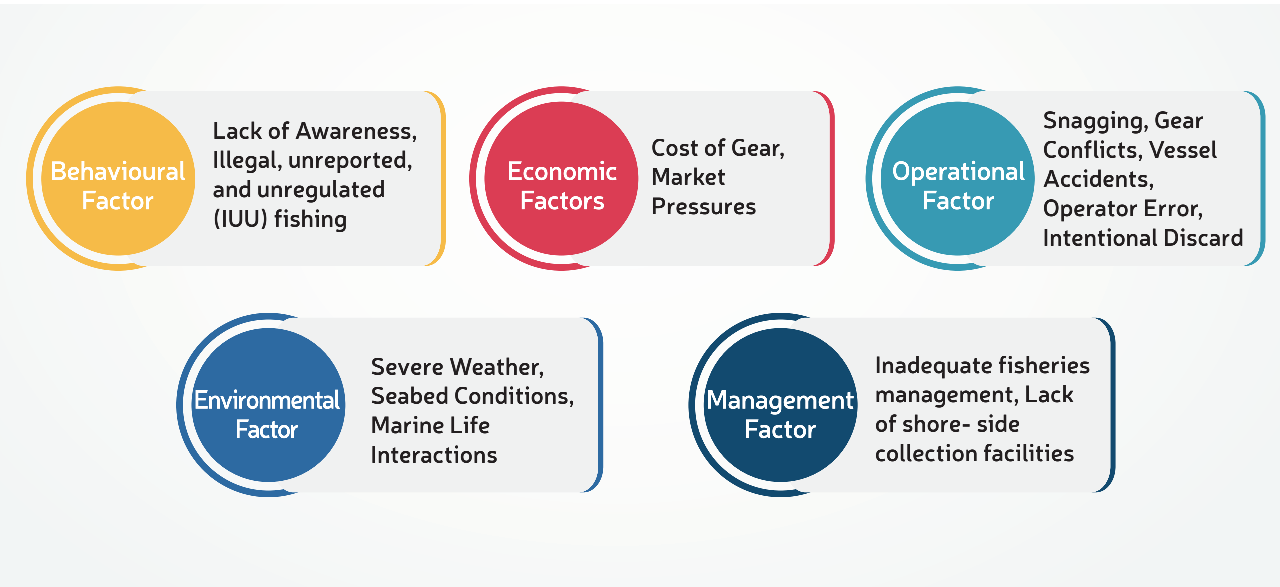


Fig.3.2: The dynamics of fishing gear loss: major causes and contributing factors

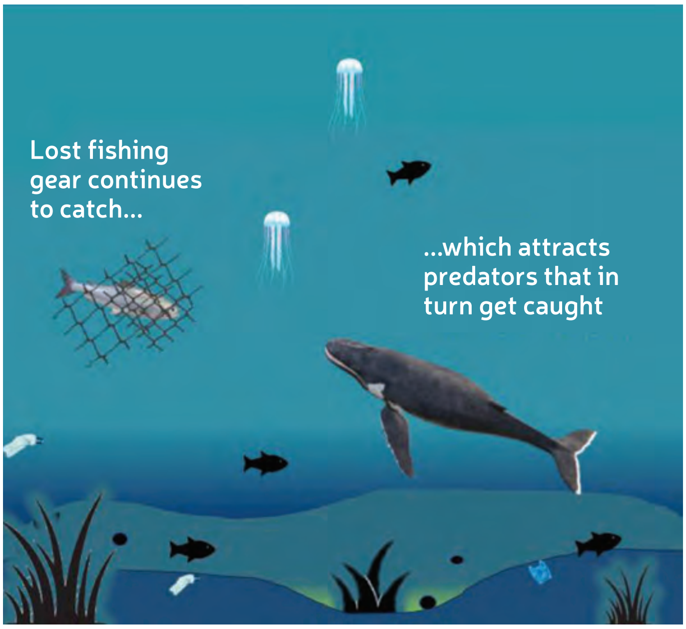


Fig.3.3: Ghost fishing: the silent threat of lost gear and its ecological consequences

Fig.3.4: The chain reaction of ghost fishing: from lost gear to predator catch

problem (Richardson et al., 2019). For instance, many fishers do not report lost equipment due to fear of penalties or lack of incentives for recovery. The ecological impacts of ALDFG are severe and long-lasting (Fig.3.3).

Ghost fishing, whereby derelict nets and traps continue to capture and kill marine organisms, remains a critical issue (Lovell, 2023). Studies have revealed that a single lost fishing net can entangle hundreds of marine species over several years, contributing to unmonitored mortality rates of commercially and ecologically important species such as lobsters, crabs, sea turtles, and cetaceans (Drinkwin et al., 2023). Moreover, ALDFG damages sensitive habitats like coral reefs, seagrass meadows, and mangroves by physical abrasion and smothering, impairing their ecological functions (Garrard et al., 2024) (Fig.3.4).

On a broader scale, ALDFG contributes to the global microplastic crisis. Over time, exposure to sunlight, wave action, and microbial activity causes synthetic fishing gear to fragment into microplastics, which are ingested by marine organisms, entering the food chain and posing potential risks to human health (Fred-Ahmadu et al., 2024). Efforts to address ALDFG are gaining momentum, with international agreements, such as the London Protocol and the Global Ghost Gear Initiative (GGGI), focusing on preventive and mitigative actions. These include promoting the use of biodegradable fishing gear, implementing gear retrieval programs, enhancing port reception facilities, and introducing financial incentives for returning damaged or unused gear. The use of technologies like acoustic pingers and Global Positioning System (GPS) trackers is also being explored to reduce gear loss and facilitate recovery. Tackling the issue of ALDFG requires a holistic approach, combining regulation, innovation, and awareness. Collaborative efforts involving governments, the fishing industry, non-governmental organizations, and local communities are critical for mitigating the impacts of ALDFG and protecting marine ecosystems from further degradation (Macfadyen et al., 2009).

3.2. End-of-Life Fishing Gear: a silent contributor to marine pollution

End-of-life fishing gear (EOLFG) refers to fishing equipment that has reached the end of its functional lifespan and is typically discarded or

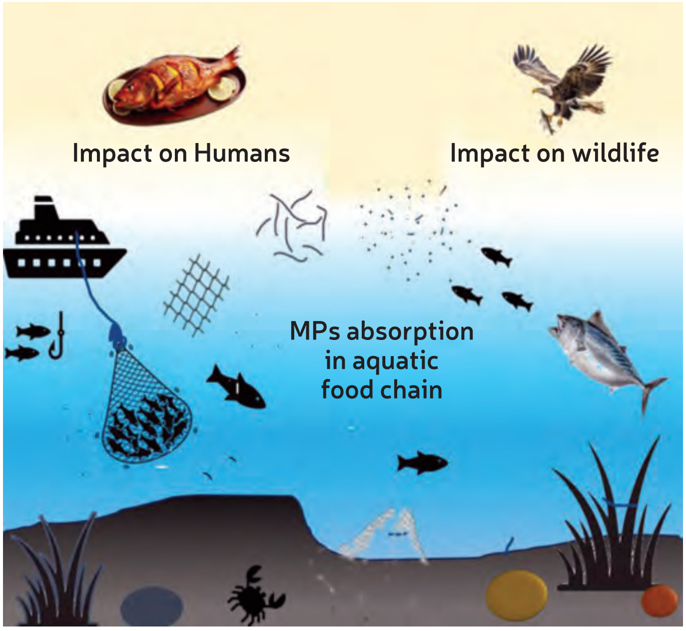


Fig.3.5: End-of-Life Fishing Gear: from ecosystem disruption to human health risks

abandoned, often becoming a significant contributor to marine pollution. EOLFG made of durable, non-biodegradable synthetic materials like nylon, polyethylene and polypropylene transitions into ALDFG when left unmanaged. The lack of adequate disposal infrastructure, high disposal costs, and logistical challenges often lead fishers to discard or abandon EOLFG at sea (Fig.3.5), andthey persist in marine environments, causing environmental, economic, and ecological damage (Havas et al., 2024). EOLFG contributes to ghost fishing, where marine organisms are trapped in abandoned gear, depleting fish stocks and endangering non-target species such as turtles, seabirds, and marine mammals. It also damages critical habitats like coral reefs and seagrass beds and breaks down into microplastics, which enter the food web, potentially impacting human health. The socioeconomic consequences include navigation hazards for maritime traffic, economic losses for the fishing industry due to ghost fishing, and diminished tourism and clean-up costs for coastal communities. In this research, EOLFG is grouped with ALDFG, as both contribute to marine pollution before ultimately being classified as marine debris. This highlights the urgent need for better lifecycle management of fishing gear, from production to disposal and potential recovery.

3.3. Impacts of fishing gear as marine litter

The impacts of ALDFG and EOLFG on marine ecosystems, economies, and human communities are extensive and causing deep concern. Both of them contribute significantly to marine pollution, and their impacts overlap in many critical ways.

3.3.1. Ecological Impacts of ALDFG and EOLFG

ALDFG and EOLFG significantly disrupt marine ecosystems, primarily through ghost fishing, where derelict nets and traps continue to capture marine life indiscriminately. This results in unmonitored and unsustainable mortality rates for numerous species, including fish, sea turtles, seabirds, and marine mammals. For instance, ghost nets in the Great Barrier Reef are responsible for entangling and killing over 10,000 marine turtles annually (Arzey et al., 2024). Furthermore, EOLFG, often discarded improperly, contributes to habitat destruction.

Critical habitats such as coral reefs, mangroves, and seagrass beds suffer physical damage from snagging or abrasion caused by derelict or discarded gear. These habitats are essential for biodiversity and ecosystem services, yet their recovery and ecological function are hindered by this persistent threat.

3.3.2. Economic Impacts of ALDFG and EOLFG

ALDFG and EOLFG pose substantial economic challenges to fisheries and coastal communities. The fishing industry suffers from depleted fish stocks due to ghost fishing, which reduces catch yields and increases competition for dwindling resources. Cleanup operations for derelict and end-of-life gear cause another significant financial burden. For example, in the North Sea, annual cleanup costs for lost or discarded fishing gear amount to millions of dollars (Mengo et al., 2023). Additionally, the replacement of lost or discarded fishing equipment adds further financial strain on fishers, particularly in small-scale operations (McIntyre et al., 2023).

Beyond economic impacts, ALDFG and EOLFG contribute indirectly to climate change. The production, transportation, and eventual loss or disposal of synthetic fishing gear involves high carbon footprints, especially given the reliance on petroleum-based plastics. Once discarded in marine environments, these materials degrade very slowly, releasing microplastics and associated greenhouse gases (methane, ethylene) under sunlight and thermal stress (Royer et al., 2018). Moreover, ghost fishing leads to the unintended capture and death of marine species, including commercially valuable and endangered organisms. This disrupts marine food webs and reduces populations of key species such as herbivorous fish and apex predators, destabilizing the ecosystems and diminishing the ocean's natural ability to store carbon through biological processes like biomass accumulation and sedimentation. Thus, addressing ALDFG and EOLFG is not only an economic imperative but also a critical climate mitigation strategy in coastal and marine resource management.

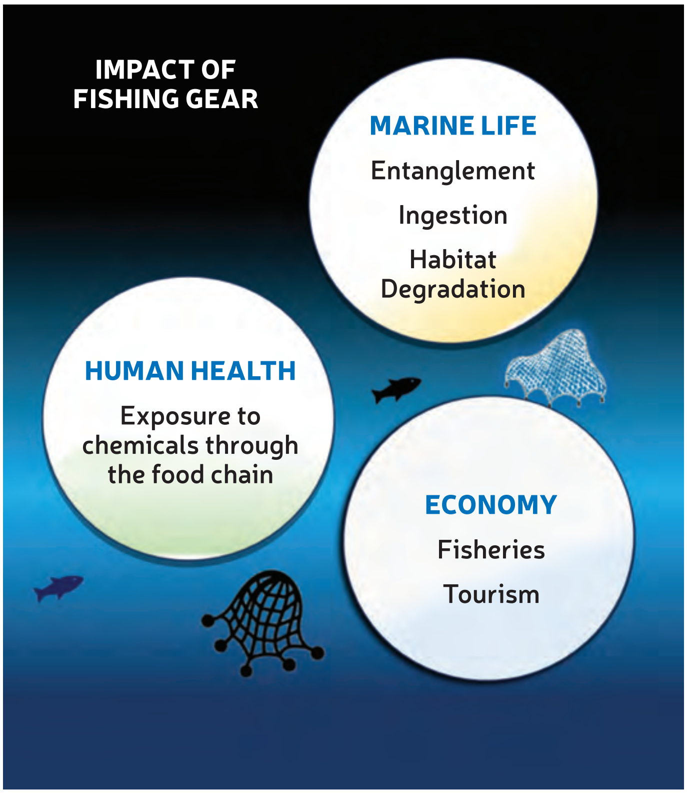


Fig.3.6: The multifarious impact of fishing gear

3.3.3. Social and Human Health Impacts of ALDFG and EOLFG

Socially, ALDFG and EOLFG create navigational hazards for fishing vessels, recreational boats, and other marine users, increasing the risk of accidents and infrastructure damage. The presence of large quantities of derelict gear also diminishes the aesthetic value of coastal and marine environments, adversely affecting tourism-dependent regions. On a broader scale, both ALDFG and EOLFG contribute to the global microplastic crisis, as degraded synthetic materials from these sources fragment into microplastics (Gallagher et al., 2023). These microplastics enter the marine food web and ultimately human diets, posing potential health risks through bioaccumulation and toxicity.

The impacts of ALDFG and EOLFG extend across ecological, economic, and social dimensions, highlighting the urgent need for effective management strategies to prevent gear from becoming marine litter (Fig.3.6). Addressing the life cycle of fishing gear and implementing sustainable disposal methods for EOLFG are critical steps in mitigating these widespread impacts.

3.3.4. The role of fishing communities

Fishing communities play a vital role in the effective utilization of the marine environment. While fisheries are recognized as major contributors to marine litter pollution (Ruiz et al., 2022), they also grapple with numerous challenges posed by this issue, which severely undermine revenues and inflate operational costs. However, fishermen are positioned to be key players in monitoring, preventing, and removing marine litter from the environment (Nguyen and Brouwer, 2022). A deeper understanding of marine litter sources particularly from the fishing and shipping industries including ALDFG is essential for seizing growth opportunities. Enhanced research and collaboration in these crucial areas can contribute to the protection of marine ecosystems and supports the long-term sustainability of the fishing industry.

4

STATUS OF MARINE LITTER POLLUTION AT GLOBAL, NATIONAL AND STATE LEVELS

4. STATUS OF MARINE LITTER POLLUTION AT GLOBAL, NATIONAL AND STATE LEVELS

Marine litter pollution has emerged as a significant environmental concern, threatening marine ecosystems, biodiversity, and human livelihoods. It extends across local, national, regional, and global scales, requiring a critical focus of research, policymaking, and action. The following sections outline the status of marine litter pollution at various levels. At the global level, marine litter pollution is pervasive, with an estimated 8-12 million tons of plastic waste entering the oceans annually. Major contributors include mismanaged plastic waste from coastal populations, industrial discharges, and shipping activities. Microplastics, ALDFG, and single-use plastics are particularly problematic (Löhr et al., 2017). International organizations such as the United Nations Environment Programme (UNEP) have been established, and initiatives like the Global Partnership on Marine Litter (GPML) have been undertaken to address this crisis through coordinated global actions (GarcíaRellán et al., 2023). However, significant gaps remain in enforcement, funding, and public awareness.

In India, a nation with an extensive coastline of 11,098.81 km, marine litter pollution is an escalating issue. A significant portion of marine litter originates from land-based sources, such as untreated sewage, urban runoff, and plastic waste from coastal cities. Fishing activities contribute notably to ALDFG in the region. The Indian government has launched initiatives like the National Marine Litter Policy and the Swachh Bharat Mission to tackle plastic waste (Pilapitiya and Ratnayake, 2024). Despite these efforts, challenges persist due to inadequate waste management infrastructure, limited enforcement of regulations, and a lack of public participation.

Tamil Nadu, a coastal state with a vibrant fishing community, is heavily impacted by marine litter pollution. Beaches and coastal waters are often littered with plastics, ALDFG, and end-of-life fishing gear, which threaten marine habitats and livelihoods. The region has witnessed localized clean-up campaigns and awareness drives led by NGOs, fishing communities, and government bodies (Lincoln et al., 2023). However, a comprehensive, state-wide strategy is required to

address the issue systematically. Tamil Nadu's policies must also align with regional and global frameworks to ensure effective implementation and long-term sustainability.

4.1. Marine litter pollution: a global perspective

Marine litter pollution is a pervasive issue, with contributions and impacts covering countries and ecosystems worldwide. China, as the largest plastic producer globally, contributes significantly to marine litter due to inadequate waste collection and recycling systems (Fürst and Feng, 2022). In India, extensive coastal regions face plastic pollution from urban runoff, unregulated waste dumping, and fishing-related litter (Robin et al., 2023). Studies highlight that Southeast Asia, notably Indonesia (10%), Vietnam (6%), Thailand (3%), Malaysia (3%) and the Philippines (6%), accounts for a significant share of marine plastic debris, primarily due to insufficient waste management infrastructure (Jambeck et al., 2015). The United States and parts of Europe, while better equipped with advanced systems, contribute to marine litter through improper disposal of single-use plastics and export of waste to developing countries, leading to leakages into the environment (Law et al., 2020).

Globally, ocean gyres such as the Great Pacific Garbage Patch have become hotspots of accumulating debris, including plastics, abandoned fishing gear, and microplastics (Rynek et al., 2024). According to an estimate, this patch alone contains over 1.8 trillion pieces of plastic, weighing approximately 80,000 metric tons (Lebreton et al., 2018). The Mediterranean Sea has been classified as one of the most polluted marine regions (2.25×10^3 to 8.50×10^6 per square kilometer) due to densely populated coastlines, intense maritime activities, and tourism (Pedrotti et al., 2022). Similarly, studies in the Arctic Ocean have revealed substantial concentrations of microplastics (2.4 items/m^3), transported through atmospheric and oceanic currents, threatening the fragile polar ecosystems (Mishra et al., 2021).

Microplastics are a growing concern, with studies indicating their presence in every marine environment studied, including remote locations like the Mariana Trench (3.3 ± 0.7 items/m^2) (Jamieson et al., 2019). A 2016 United Nations report estimated that more than 800 marine species are directly affected by plastic pollution, with consequences ranging from ingestion and entanglement to habitat degradation (Murray and Cowie, 2011). In South Korea, coastal waters show high levels of microplastic contamination (130,000 particles/kg d.w.) often linked to industrial discharges and maritime activities (Eo et al., 2022). In Japan, the total plastic input ranges widely from 210 to 4,776 tons/year, with a map indicating that plastic emissions are particularly high in densely populated and highly urbanized regions, such as the Tokyo metropolitan area and other major urban centers like Nagoya and Osaka (Nihei et al., 2020). Studies from Australia highlight the impact of ALDFG, commonly referred to as ghost nets, on marine species such as sea turtles and dugongs (Hardesty et al., 2021).

Global studies estimate that 8 to 11 million metric tons of plastic waste enter the oceans annually, equivalent to dumping a garbage truck's worth of plastic every minute. Unless intervened, this figure could increase to 23 to 37 million metric tons by 2040, tripling the volume of ocean plastic (Ng et al., 2023). Reports from Africa emphasize the role of unregulated coastal dumpsites in litter leakage, exacerbated by limited waste collection coverage in urban and rural areas (Zhang et al., 2024). In South America, countries like Brazil face challenges from tourism-driven pollution and the disposal of untreated sewage into coastal waters (Soares et al., 2021).

Efforts to address marine litter have gained momentum globally. The European Union has enacted bans on single-use plastics, which constitute 85% of marine litter, while countries like Kenya and Bangladesh have imposed strict bans on plastic bags (Williams and Rangel-Buitrago, 2022). In Norway, innovative deposit-return systems for beverage bottles have achieved a 97% recycling rate (Picuno et al., 2025). Community-driven clean-ups, such as those spearheaded by organisations in the Maldives, emphasize the role of eco-tourism and waste reduction in vulnerable island ecosystems (Choosuk et al., 2024). Similarly, Chile and Peru are adopting sustainable fishing practices to reduce discarded gear and marine debris (Deville et al., 2023).

These studies underscore the urgent need for

integrated global action, including improved waste management systems, international treaties like the Global Plastic Treaty, and increased public awareness. Collaborative research and innovation, such as leading to the development of biodegradable materials and enhanced recycling technologies, are essential to curb this growing environmental crisis. The trajectory of marine litter pollution serves as a warning that in the absence of concerted global efforts the economic, ecological, and health-related costs will escalate dramatically in the coming decades.

4.2. Status of marine litter pollution in India

Marine litter pollution poses a significant environmental threat to India's extensive coastline (11,098.81 km), covering nine coastal states and four Union Territories. The major components of marine litter include plastics, microplastics, ALDFG, and waste emanating from urban and industrial activities (Pattiaratchi et al., 2022). India generates approximately 3.4 million tons of plastic waste annually, with 60% of this waste entering the marine environment due to insufficient waste management infrastructure (Hossain et al., 2022).

The issue of marine litter pollution is widespread, with numerous studies documenting high levels of plastic and microplastic contamination along Indian coasts. Research indicates that microplastic concentrations in Indian coastal waters range from 68 to 603 particles per kg of sediment, with urban centers such as Chennai, Mumbai, and Kochi being notable hotspots (Veerasingam et al., 2020). Additionally, Tiwari et al. (2019) reported that microplastic concentrations in beach sands along the Indian coast ranged from 45 to 220 particles per kg of dry sand. A 2021 study by the Central Marine Fisheries Research Institute (CMFRI) found that plastics made up 87% of the marine litter collected from Indian waters, including single-use plastics, multilayer packaging, and fishing nets (Nammalwar, 2021). Although Jambeck et al. (2015) referred to global marine litter statistics, the trends observed in land-based sources (such as urban sewage, solid waste disposal, agricultural runoff, and tourism) and sea-based sources (including ALDFG and port activities) apply to many regions, including India's coastal areas.

Several coastal states in India are grappling with significant marine litter problems. In Gujarat, for example, regions such as Jamnagar, Veraval, and Porbandar suffer from heavy pollution, primarily from plastic and industrial waste (Mahadevia, 1999). The India-Norway cooperation project on capacity building for reducing plastic and chemical pollution (INOPOL, 2022) highlights how rivers in Gujarat transport plastic pollution from land-based sources, exacerbating the accumulation of plastic waste in marine environments. In fact, a 2020 study by the Energy and Resources

Institute (TERI) revealed that over 250 tons of plastic waste enter Gujarat's coastal waters annually, primarily from industrial effluents and urban waste (TERI, 2020).

Mumbai, a major coastal city, generates more than 7,000 metric tons of waste daily, a significant portion of which is plastic. This waste contributes to severe littering on beaches like Juhu and Versova (Resilient Cities Network, 2024). Goa, with its 101-km coastline, struggles with significant plastic pollution, especially on popular beaches like Calangute and Baga. A study found that Calangute Beach had 66.4% plastic waste, while Baina Beach had 76.5% plastic waste. These beaches experience heavy littering during peak tourist seasons, posing a serious environmental challenge (Khan, 2024; The Goan, 2024). Similarly, Karnataka's 300-km coastline, which includes Mangalore and Karwar, is prone to significant litter accumulation, mainly from fishing activities and port operations. Common plastic items include low-density polyethylene and polystyrene. A study by Sridhar et al. (2009) found that food-based plastic debris accounted for the highest percentage (43%), followed by domestic waste (28%), fishing-related debris (18%), and other types (11%). Kerala's 590-km coastline, particularly areas like Kochi and Kollam, is heavily impacted by fishing gear-related waste and urban litter, which together make up over 50% of marine debris. A survey conducted across six fishing beaches in Kerala revealed that beaches with higher fishing activity had four times more plastic waste than those with lower activity. Additionally, fishing-related plastic debris was more prevalent in the post-monsoon season than the monsoon season (Daniel et al., 2020).

Tamil Nadu, with its 1,068.69 kmcoastline, faces severe litter accumulation, especially during the post-monsoon period. Marina Beach in Chennai has been reported to have up to 125 plastic items per 100 m of coastline (Kumar et al., 2016). In a separate study by the Citizen Consumer and Civic Action Group (CAG, 2017), 8,742 pieces of plastic waste were observed over just a 200-m stretch during two hours. Andhra Pradesh, with a

coastline of 974 km, also experiences high levels of marine litter due to industrial discharges and port activities, particularly in cities like Visakhapatnam and Kakinada (TOI, 2023). Odisha's 480-km coastline, including hotspots like Puri and Paradeep, faces significant plastic pollution, particularly during pilgrimages. Over 50 tons of plastic waste are recorded annually in Puri, where the impact of plastic debris on Olive Ridley turtles poses a serious survival threat due to entanglement and ingestion (Duncan et al. 2017; Barik et al., 2024).

In West Bengal, riverine inputs from the Ganga-Brahmaputra basin significantly contribute to marine litter, particularly in the Sundarbans and Digha regions, where nearly 60% of the debris comes from the Ganga River. The Ganga alone contributes over 15,000 tons of waste annually to the Bay of Bengal (National Mission for Clean Ganga, 2020). Union Territories also face challenges related to marine litter. Daman and Diu are impacted by litter from tourism, while the Lakshadweep and the Andaman & Nicobar Islands have to deal with debris transported by ocean currents, including ALDFG and plastic bottles (Kaviarasan et al., 2020; Patra et al., 2023). Shankar et al. (2024) found that 80% of marine litter in the Andaman and Nicobar Islands consisted of plastic packaging and fishing gear, posing significant risks to coral reefs and marine biodiversity. Puducherry's beaches also experience litter accumulation, primarily from tourism and urban activities, with microplastic levels in sediments averaging 72.03 ± 19.16 particles per 100 g of dry weight (Dowarah and Devipriya, 2019).

India's Draft National Marine Litter Policy (MoES, 2025) outlines a multi-tiered approach to tackle marine plastic pollution through prevention, extended responsibility, and inclusive governance (Mongabay India, 2025). Key strategies include phasing out single-use plastics, improving waste segregation and coastal collection systems, and expanding Extended Producer Responsibility (EPR) to hold plastic producers accountable for post-consumer waste, including marine leakage (Sambandam et al., 2024). Shared responsibility models may also apply to fisheries and tourism (MoEFCC, 2021).

The policy emphasizes long-term monitoring by NCCR and State Pollution Control Boards, supported by microplastic assessments to guide interventions (MoES, 2024). Implementation requires coordination among central ministries, states, panchayats, and coastal communities through region-specific action plans. Community participation is encouraged via derelict gear recovery, outreach programs, and sustainable tourism initiatives such as the Blue Flag beach certification (MoEFCC, 2018; MoEFCC, 2021).

Studies now estimate that India generates approximately 9.3 million tons of plastic waste annually (Cottom et al., 2024), becoming one of the world's largest producers. Gaps in collection and disposal systems—particularly along the coastline—underscore the need for coordinated, policy-driven interventions. While the Draft National Marine Litter Policy outlines a solid strategic framework, its success will heavily depend on strong enforcement, sustained investment in coastal waste infrastructure, community-led efforts, and rigorous scientific monitoring to safeguard India's marine ecosystems.

4.3. Status of marine litter pollution in Tamil Nadu

Tamil Nadu, with its 1,068.69 km coastline, faces a growing challenge of marine litter pollution driven by urbanization, industrial activities, fishing, and tourism. Plastics dominate the waste, comprising over 70% of the total debris, with primary contributors being single-use plastics, ALDFG, and tourism-related litter (Mishra et al., 2025). Coastal areas such as Marina Beach in Chennai are particularly impacted, with post-monsoon litter accumulation reaching up to 30 tons, primarily consisting of plastic bags, bottles, and food wrappers (Pradhan et al., 2018). Sunitha et al. (2021) identified alarming levels of microplastic pollution at Marina Beach, with concentrations reaching up to 1,620 items per kg in wet sediment and 1,540 items per kg in dry sand. In addition, studies by Ramesh and Nagalakshmi (2023) and Robin et al. (2021) emphasized the severe impact of plastic debris along Chennai's coast.

The Gulf of Mannar, a biologically sensitive region, faces heightened risks from plastic pollution. A study on the reef areas found that ALDFG represented a significant portion (43.17 ± 5.48%) of marine debris. Fishing nets particularly pose a substantial threat to marine life, including corals and fish, by causing entanglement (Patterson et al., 2019). Furthermore, microplastic pollution has become an emerging threat to the region's reef ecosystems, with plastic ingestion by marine species leading to suffocation and entanglement, which disrupts biodiversity and ecosystem health (Ashrafy et al., 2023). Research by the Suganthi Devadason Marine Research Institute (SDMRI) in 2022, under the MARESSOL project, revealed that nearly 50% of the marine litter in the Gulf of Mannar consists of fishing gear, with ALDFG contributing 74% of the total weight of the debris (MARESSOL, 2022). A study by Mengo et al. (2023) further highlighted the prevalence of fishing-related debris, such as discarded nets, monofilament lines, and thermocol, particularly in areas with intensive fishing activity.

Tourism significantly enhances seasonal spikes in litter. Popular tourist spots like Mahabalipuram, Kanniyakumari, and Elliot's Beach report litter densities exceeding 500 items per 100 m during peak tourist seasons (Karthikeyan & Subagunasekar, 2023; Kasa et al., 2025). A study by Krishnan et al. (2022) across 33 beaches between 2019 and 2021, and 75 beaches in 2022, found that tourism and fishing were the major

sources of beach pollution. Perumal et al. (2023) reported that plastics constituted 65.08% of the total marine litter on the Kanniyakumari coast, with 96.87% of it originating from land-based sources.

Microplastic contamination remains a pressing environmental issue along Tamil Nadu's coastline. Ramesh and Nagalakshmi (2023) reported sediment microplastic concentrations ranging from 180 to 600 particles per kg. Further studies have indicated pervasive microplastic pollution along the Tuticorin coast, with abundance ranging from 19 ± 18.62 to 78.55 ± 95.17 items per kg, posing significant risks to the marine ecosystem (Keerthika et al., 2022). Sunitha et al. (2021) also highlighted the widespread presence of microplastic particles along the Bay of Bengal coastal stretch. Studies by Harikrishnan et al. (2023) on commercially important fish species from Adyar and Ennore regions found microplastics in the gills and guts of fish, averaging 3.2 to 7.6 microplastic particles per fish. Both carnivorous and planktivorous species were affected. Jeyasanta et al. (2020) reported microplastic contamination in the Rameswaram region, with microplastic abundance varying from 24 ± 9 to 96 ± 57 items per liter in water, and 55 ± 21 to 259 ± 88 items per kg in sediment, indicating the widespread presence of plastics in various habitats, including coral reefs, seagrass beds, and shoreline areas. Further research by Ponmani et al. (2024) on mangroves along the Tuticorin coast revealed that over 81% of marine litter comprised plastic items, with single-use plastics being the most prevalent. Such debris, particularly abandoned or entangled plastic materials, can obstruct pneumatophores and damage mangrove branches, thereby impairing the health of mangrove ecosystems and highlighting the detrimental effects of marine litter. Kalaiselvan et al. (2023) also reported the presence of microplastics in commercially important fish species along the Tuticorin coast, with concentrations ranging from 0.00 to 1.80 ± 1.19 particles per fish, indicating the potential entry of microplastics into the food chain.

In summary, addressing marine litter pollution in Tamil Nadu requires urgent and coordinated efforts involving stricter regulations, public awareness campaigns, and sustainable waste management practices to protect its precious coastal and marine environments.

5

IMPACTS OF MARINE LITTER

5. IMPACT OF MARINE LITTER

Marine litter pollution has far-reaching repercussions, affecting ecosystems, climate, economies, and human and animal health. This section explores the various dimensions of its impact.

5.1. Impact on the environment

Marine litter, especially plastics, has a profound impact on the environment, affecting both aquatic and terrestrial ecosystems. It disrupts biogeochemical cycles, spreads invasive species, and introduces harmful pollutants into the food chain. Marine debris poses significant risks to biodiversity, ecosystem stability, and human health by altering / contaminating a range of compartments from coastal waters and sediments to groundwater (Landrigan et al., 2020). The accumulation of litter in oceans and coastal areas not only damages marine habitats but also disrupts essential ecological processes, highlighting the urgent need for comprehensive action to address this growing environmental challenge.

5.1.1. Impact on coastal waters

Marine litter has significant consequences for coastal waters, altering both the physical and chemical properties of the environment. As plastic and other debris accumulate, they impede the penetration of sunlight, which is vital for photosynthesis in aquatic plants. This reduces oxygen production, directly impacting the health of marine ecosystems and the organisms that rely on them. The presence of debris in the water also interferes with water circulation, disrupting natural flow patterns that are crucial for ecosystem stability. In addition to physical disruption, marine litter releases harmful chemicals as it breaks down. Plastics, for example, leach toxic substances such as heavy metals, persistent organic pollutants (POPs), and other contaminants into the surrounding waters. These pollutants accumulate in the food chain, posing risks to marine life, birds, and humans who consume seafood. Over time, these chemical contaminants further degrade water quality, causing long-term

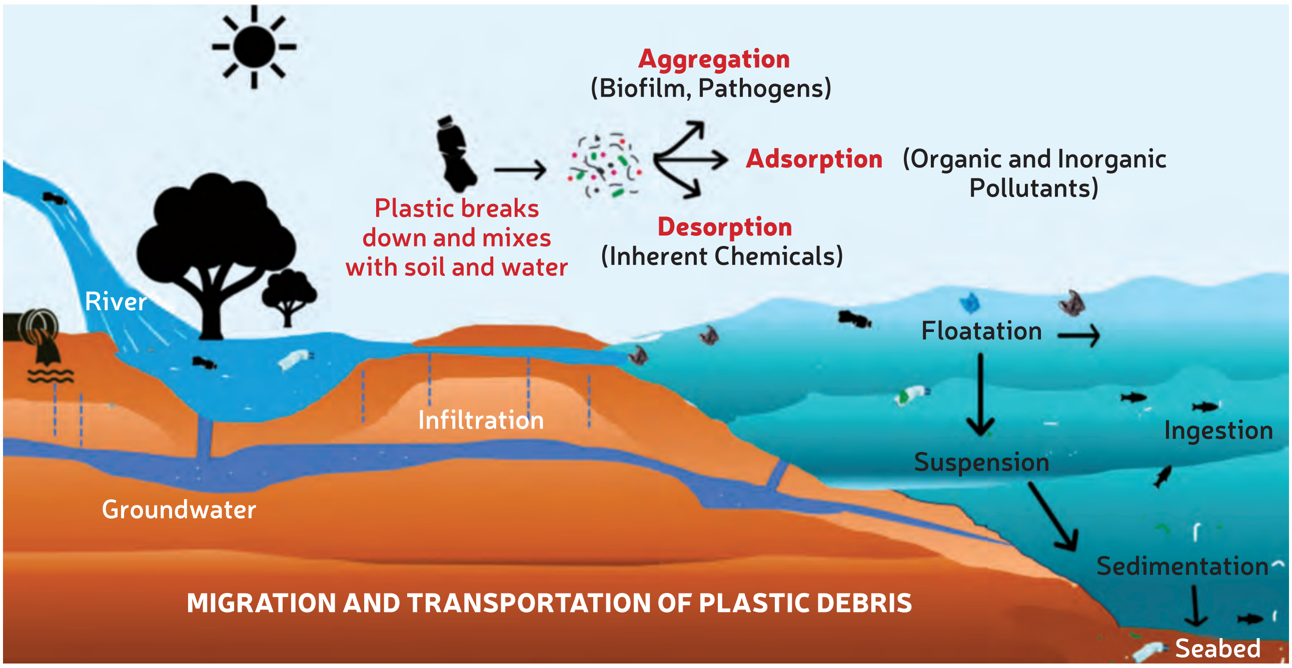


Fig.5.1: Plastic debris movement: coastal waters, groundwater, and sediment transport mechanisms

damage to the marine environment (Rangel-Buitrago et al., 2022).

5.1.2. Impact on groundwater

Groundwater is often considered isolated from surface water pollution. Marine debris, particularly plastics, poses a growing threat to underground water reserves. Over time, plastics and other debris from coastal areas can seep into the soil, affecting the integrity of groundwater. When marine litter, particularly synthetic material, decomposes, it releases microplastics and other contaminants that can infiltrate the groundwater system. Once these pollutants enter the groundwater, it is next to impossible to trace and remove them, leading to long-term contamination. In many coastal areas, groundwater serves as a vital source of drinking water and irrigation for agriculture. Contaminants from marine debris, including microplastics, toxic chemicals, and heavy metals, can compromise the quality of groundwater, affecting both human health and agricultural productivity. Microplastics, which are often invisible to the naked eye, have been detected in groundwater samples, underscoring the risk of groundwater contamination from marine litter. The presence of these pollutants in groundwater can lead to the accumulation of harmful substances in drinking water supplies, posing serious health risks over time (Singh et al., 2024; Li et al., 2021).

5.1.3. Impact on coastal sediments

Coastal sediments play a crucial role in maintaining the health of marine ecosystems, but the accumulation of marine litter significantly alters their structure and function. Large debris, such as plastic bottles, fishing gear, and synthetic materials, physically disrupts the natural movement and deposition of sediments, which can affect coastal landforms and erosion patterns. The accumulation of litter prevents proper sediment shifting, leading to changes in the landscape and potentially increasing coastal erosion. In addition to physical disruptions, marine litter alters the permeability of coastal soils, preventing water from being effectively filtered (Harrison et al., 2024). This disruption impacts the flow of both groundwater and surface water into the sediments, reducing water quality and depleting oxygen levels (Fig.5.1). Such changes can have detrimental effects on burrowing organisms and other species that rely on healthy sediments for shelter and sustenance (Landrigan et al., 2020).

5.2. Impact on human and animal health

Marine litter poses significant threats to both human and animal health, causing widespread ecological harm and direct risks to well-being. Animals, particularly marine species, suffer from entanglement, ingestion of plastics, and suffocation, leading to injury, death, and the disruption of ecosystems. For humans, the consumption of contaminated seafood and exposure to microplastics raise serious health concerns, including the introduction of potential toxins and pathogens (Lincoln et al., 2022). Additionally, marine debris contributes to habitat destruction, further jeopardising biodiversity and vital resources (Nama et al., 2023). Understanding these impacts is crucial for developing strategies to mitigate the health risks associated with marine litter.

5.2.1. Physical impact – entanglement

Entanglement in marine debris, especially discarded fishing gear, poses significant risks to marine animals. It restricts movement, making it difficult for animals to swim, hunt, or escape predators, often resulting in severe injuries, infections, amputations, or even death (Duncan et al., 2017). For marine mammals, entanglement in ghost gear (such as lost fishing nets) can be fatal, as it continues to trap animals long after it has been discarded. Ghost gear is one of the deadliest forms of marine plastic pollution, and it can entrap marine life for years, as some nets remain intact for decades (Gunasekaran et al., 2024). In the Salish Sea, over 260 species, including marine mammals and birds, have been caught in lost fishing nets, with over 2.5 million marine vertebrates estimated to have been killed between 2002 and 2009 (Hardesty et al., 2015). Even small entanglement rates can lead to significant population impacts, especially when individuals of reproductive age are affected. For humans, discarded fishing gear and marine debris also pose risks, potentially damaging fishing vessels or causing accidents that threaten livelihoods and safety (Arabi et al., 2023).

5.2.2. Ingestion

Marine animals often mistake plastic debris for food, leading to dangerous health consequences. Ingesting plastics can cause digestive blockages, malnutrition, internal injuries, and even death. Moreover, plastics adsorb harmful chemicals from the surrounding environment, which can enter the food chain when consumed by marine species. When ingested by smaller organisms, microplastics bioaccumulate up the food chain, ultimately impacting human health when seafood is consumed.

5.2.3. Suffocation and smothering

Plastic debris, such as bags and sheets, can obstruct the respiratory pathways of marine animals, leading to suffocation. This is particularly dangerous for marine mammals, fish, and reptiles. Additionally, debris that settles on the seafloor can smother important marine habitats like coral reefs and seagrass beds, disrupting ecosystems and further endangering marine life. Debris in coastal areas can pose significant risks to water activities, increasing the likelihood of accidents and drowning (Walther & Bergmann, 2022).

5.2.4. Spread of invasive species and pathogens

Marine litter acts as a transport mechanism for invasive species and pathogens, further harming ecosystems. Plastic debris can carry non-native organisms across vast distances, disrupting local ecosystems and causing biodiversity loss (Rapa et al., 2024). Floating debris can also harbour harmful microorganisms, which pose a risk to marine animals and humans. These pathogens can be transmitted through seafood consumption or by exposure to contaminated water, creating a further health hazard (Bhuyan, 2022). Species like crabs (Rech et al., 2018) and corals (Mantelatto et al., 2020) are often transported via plastic debris, with rafting organisms moving as far as 100 km through ocean currents and winds (Garcia-Vazquez et al., 2021). This transportation enables species to colonise new regions, leading to environmental damage and potential economic losses. Different types of marine litter attract

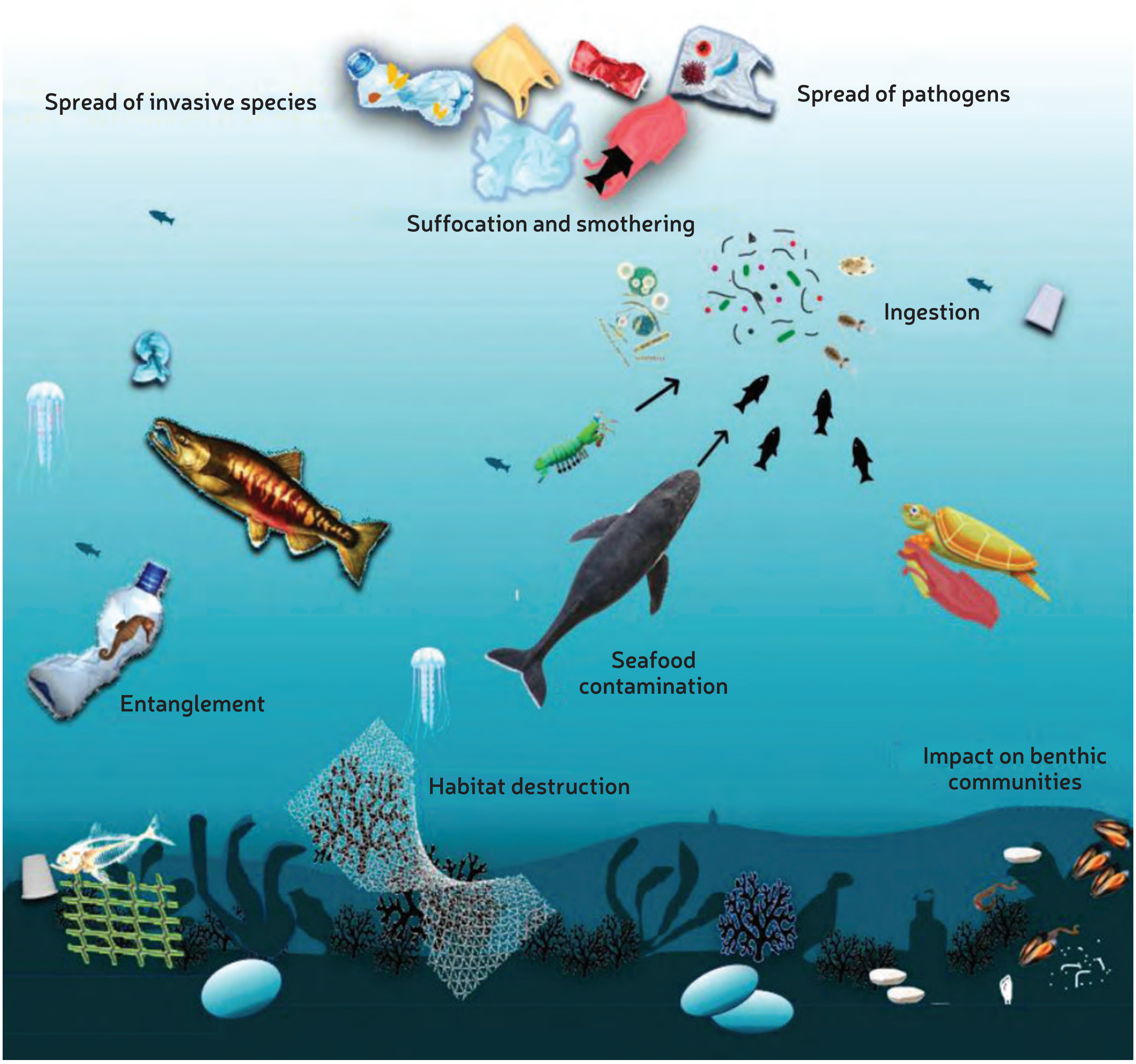


Fig.5.2: The many threats of marine debris

specific organisms (Fig. 5.2). Furthermore, maritime traffic and port activities contribute significantly to the movement of non-native species, underscoring the need for comprehensive measures to manage marine litter and prevent the spread of invasive species (Kannan et al., 2023).

5.2.5. Biogeochemical cycles

Marine litter, particularly plastics, disrupts biogeochemical cycles in aquatic and terrestrial environments. In the water, plastic accumulation affects processes like mineralization and demineralization. Resuspension of minerals by plastics can contribute to eutrophication and excessive algal growth (Chia et al., 2020). Plastics floating on the water's surface reduce light penetration, which impacts dissolved oxygen levels and water quality, ultimately disrupting biodiversity (Thushari and Senevirathna, 2020). On the sediment, marine litter interferes with sediment's ability to sequester carbon and hinders other biogeochemical processes (Han et al., 2023).

5.2.6. Habitat destruction

Marine litter, including large debris and microplastics, contributes to significant habitat destruction in crucial marine ecosystems. Seagrass beds, coral reefs, and mangroves—key habitats for marine biodiversity—suffer from structural damage, which reduces their ability to support a wide range of species. This habitat degradation has economic ramifications, particularly for fisheries and coastal tourism, industries that rely heavily on these ecosystems. The destruction of these habitats can lead to the collapse of local economies, particularly in regions dependent on healthy marine environments (Biswas et al., 2024).

5.2.7. Benthic communities

Coastal sediments are home to a rich diversity of benthic organisms, including molluscs, crustaceans, and various types of worms and other invertebrates. These organisms rely on the health of the sediments for food, oxygen, and shelter. The presence of marine litter can disrupt these ecosystems by physically altering the habitat and introducing harmful pollutants. Marine debris can smother benthic organisms, particularly those that live on or within the sediments. The accumulation of plastic and other debris can block access to oxygen and food, causing stress to these organisms.

5.2.8. Chemical impact

Plastics are inherently toxic due to the various chemical additives such as plasticizers, flame retardants, phthalates, and per- and polyfluoroalkyl substances (PFAS) and contaminants, including some known endocrine disruptors that may be harmful even at extremely low concentrations for marine biota, thus posing potential risks to marine ecosystems, biodiversity and food availability. These harmful chemicals can leach into the environment and pose risks to species that ingest microplastics (Jeong et al., 2024). In aquatic ecosystems, plastics can adsorb persistent toxic substances already present in the environment, particularly due to the increased surface area-to-volume ratio of microplastics (Qaiser et al., 2023). This process allows plastics in marine environments to act as a sponge, concentrating bacteria and environmental pollutants—including heavy metals, persistent organic pollutants (POPs), and endocrine-disrupting chemicals (EDCs)—from seawater (Rochmann et al., 2013). As a result, they create a complex mixture of toxic substances that can adversely affect various marine species that come into contact with them. Marine plastic debris also acts as a vector for toxic chemicals, including (Fig. 5.3):

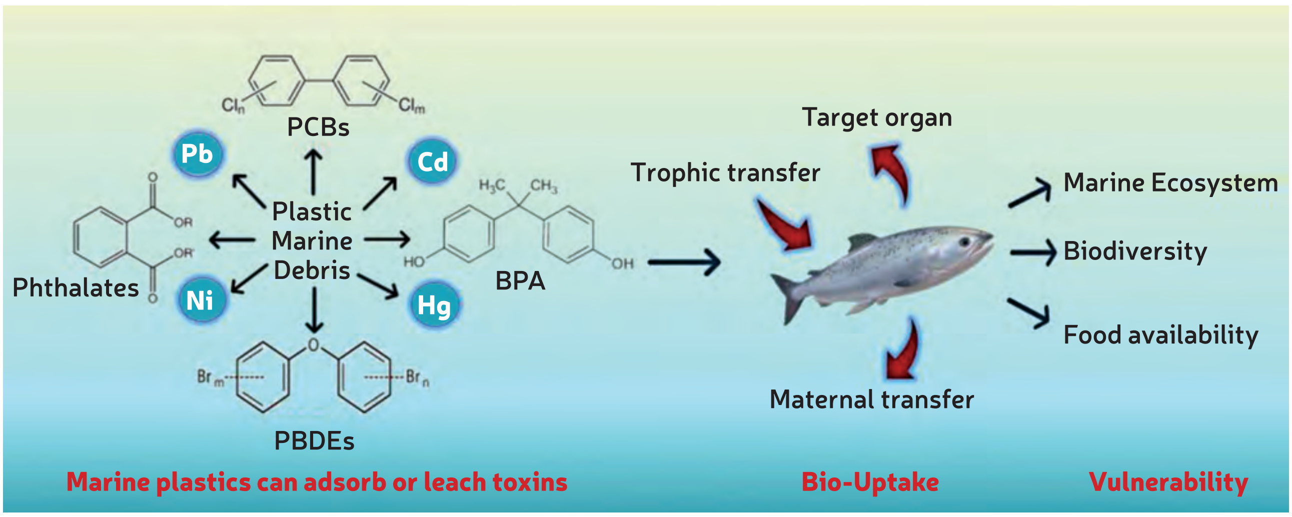


Fig.5.3: Toxic threat of marine plastics: adsorption, leaching, bioaccumulation, and ecological vulnerability

- **Persistent Organic Pollutants (POPs):** Plastics adsorb harmful chemicals like Polybrominated Diphenyl Ethers (PBDEs), polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), and polycyclic aromatic hydrocarbons (PAHs), which bioaccumulate in marine organisms and can enter the human food chain, concentrating in fatty tissues (Primost et al., 2024).

- **Endocrine-Disrupting Chemicals (EDCs):** Chemicals like BPA and phthalates, found in plastics, can disrupt hormonal systems and lead to serious health issues when humans consume contaminated seafood (Stiefel & Stintzing, 2023).

- **Heavy Metals:** Plastics can accumulate metals such as lead, cadmium and mercury through biofilm formation on their surfaces, which are harmful to marine life and humans. Mercury, in particular, can cause neurological damage, especially in pregnant women and children (Mantelatto et al., 2020).

5.2.9. Bioaccumulation and biomagnification

As a result, seafood consumed by humans can contain high concentrations of harmful substances, such as POPs, EDCs, and heavy metals. Fish, shellfish, and other marine organisms are critical sources of protein and other nutrients for human populations, especially in coastal and island communities. However, the ingestion of contaminated seafood can expose humans to a range of health risks, including neurological disorders, reproductive health issues, and cancers. The risks associated with bioaccumulation are particularly a matter of concern for vulnerable populations, such as pregnant women, infants, and children, who are more susceptible to the harmful effects of these chemicals (Ochoa-Esteso et al., 2024).

5.3. Impact on climate change

Marine litter, particularly plastics, plays a manifold role in influencing climate change. While plastic pollution is often viewed primarily as an environmental and ecological issue, its impact extends to the global climate system, influencing both the physical environment and atmospheric conditions in ways that exacerbate climate change (Seyyedi et al., 2023). Below are the key ways in which marine litter interacts with and contributes to climate change:

5.3.1. Contribution to greenhouse gas emissions

Plastic waste in the ocean can indirectly contribute to climate change by emitting greenhouse gases (GHGs) through the process of degradation. While plastics themselves are generally inert, certain types of plastics, such as polyethylene and polypropylene, when exposed to environmental conditions like sunlight and seawater, can degrade over time and release methane and ethylene, two potent greenhouse gases. This occurs through a process called photodegradation, where UV radiation from the sun breaks down the chemical structure of plastics. Over the years, the cumulative release of these gases could potentially add to the overall atmospheric concentration of GHGs, further accelerating global warming (Sharma et al., 2023).

Additionally, plastic production is a major contributor to carbon emissions. The production of plastic materials requires significant energy, mostly derived from fossil fuels. According to some estimates, the production of plastic materials is responsible for about 4-8% of global oil consumption, leading to increased emissions of carbon dioxide (CO_2), one of the primary greenhouse gases (Bauer et al., 2022). When plastic waste accumulates in the oceans, it essentially represents a long-term carbon sink that eventually leaches carbon-based chemicals into marine ecosystems, indirectly contributing to the climate change cycle (Lincoln et al., 2022).

5.3.2. Ocean carbon sequestration and the disruption of the carbon cycle

The ocean plays a critical role in the Earth's carbon cycle, absorbing a significant portion of atmospheric CO_2. Marine organisms, particularly phytoplankton, absorb CO_2 during photosynthesis and help regulate global carbon levels (Fig.5.4). However, marine litter, especially large pieces of plastic debris, can interfere with this process.

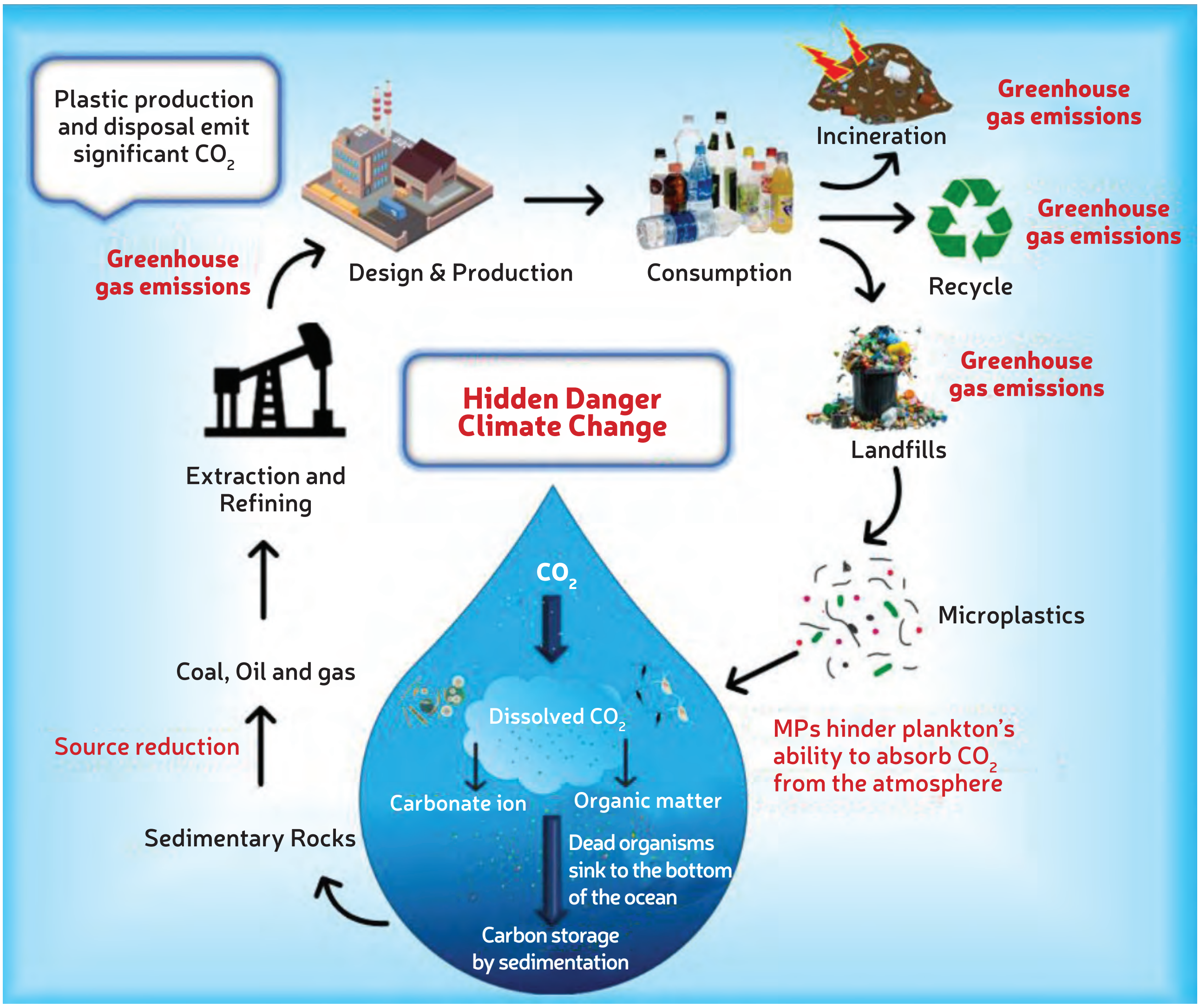


Fig.5.4: Hidden dangers of plastics: climate change, CO_2 emissions, and plankton disruption

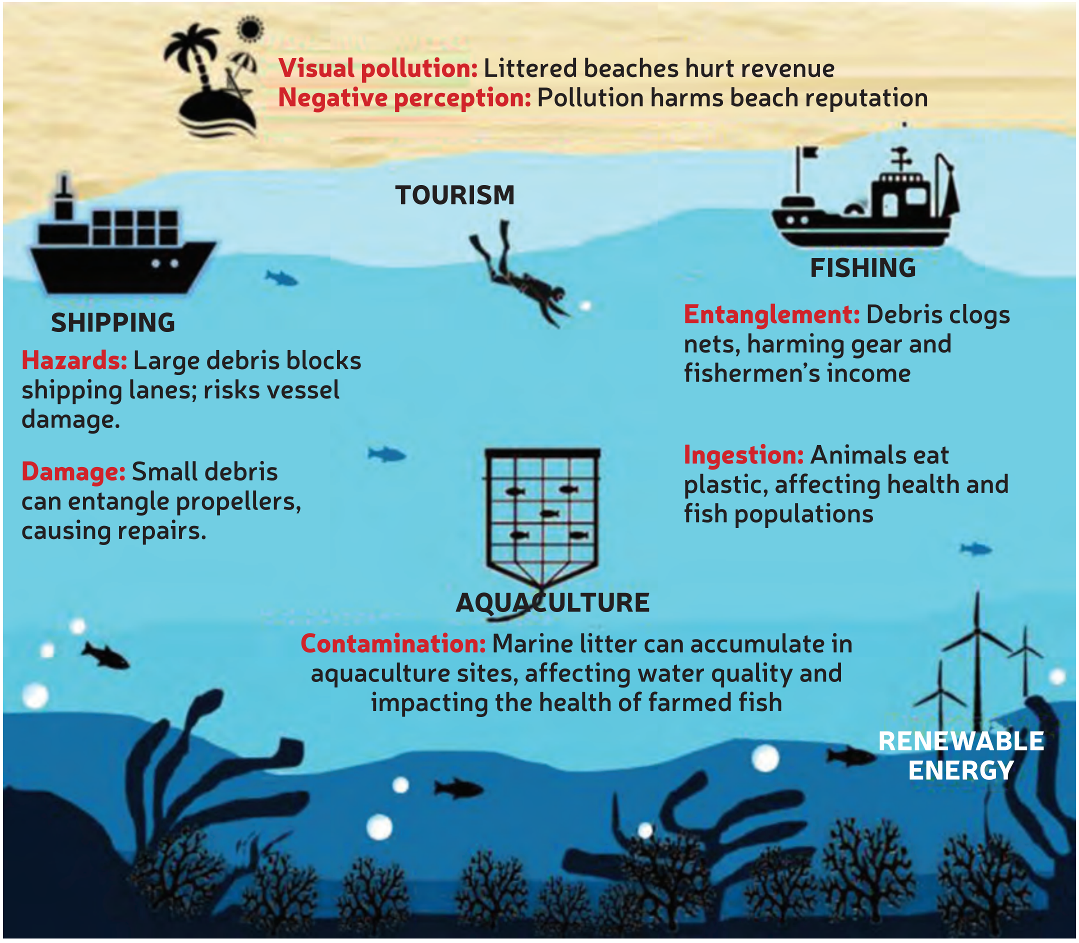


Fig.5.5: Economic impacts of marine litter on the blue economy

- **Impediment to phytoplankton growth:** Large plastic debris, including floating plastic waste, can block sunlight from reaching surface waters, thus disrupting the photosynthetic processes of phytoplankton. Populations of phytoplankton are vital members of the marine food chain in capturing carbon through photosynthesis and contributing significantly to the ocean's role as a carbon sink. By obstructing sunlight and potentially causing a decline in plankton populations, marine litter undermines the ability of oceans to absorb CO_2 from the atmosphere, exacerbating the greenhouse effect and climate change (Tuuri & Leterme, 2023).

- **Microplastic and carbon sequestration:** Microplastics can also impact marine ecosystems by affecting the organisms that contribute to the ocean's ability to sequester carbon. Microplastics may alter the behaviour of zooplankton and other marine species, affecting their feeding and metabolism. This could disrupt the "biological pump," which is the process through which carbon is transported from the surface waters to the deep ocean through the feeding and waste processes of marine organisms. This disruption could reduce the ocean's efficiency in carbon sequestration, resulting in more CO_2 remaining in the atmosphere and worsening climate change (Sunil et al., 2024).

5.4. Impact on the blue economy

Marine litter has a profound impact on the blue economy, affecting key sectors such as fisheries, tourism, shipping, renewable energy, and aquaculture (Thushari and Senevirathna, 2020) (Fig.5.5). It disrupts marine ecosystems, threatening biodiversity and the availability of fish,

which in turn harms the fishing industry and livelihoods reliant on marine resources. Contaminants from marine debris also enter the food chain, posing health risks to both marine life and humans. In tourism, marine litter diminishes the appeal of beaches and coastal areas, leading to lower tourism revenues and additional clean-up costs. Shipping industries face damage to vessels, clogged port facilities, and higher maintenance expenses, while the spread of non-native species via debris can disrupt shipping routes and goods transport.

Additionally, marine litter poses challenges to renewable energy facilities like wind turbines and wave converters, and contaminates aquaculture sites, affecting farmed species and causing economic losses in the industry (Abalansa et al., 2020). Overall, marine litter hampers sustainable growth within the blue economy by negatively impacting marine resources, ecosystem services, and economic activities tied to healthy oceans.

5.5.Impact on coastal socioeconomics and livelihoods

Quantifying the full economic cost of marine litter is a challenging task due to its diverse and far-reaching impacts on economic, social, and environmental systems. While some costs, such as beach clean-up expenditures and the replacement of damaged fishing gear, are direct and measurable, others such as the degradation of ecosystems and the reduction in quality of life are less tangible and harder to quantify.

Moreover, in view of the spatial and temporal nature of these impacts the full extent of the costs may not be immediately apparent, yet they remain crucial to long-term sustainability (Iglesias et al., 2023). Coastal communities, particularly those dependent on marine-based industries, face significant challenges due to marine litter. Marine litter severely impacts livelihoods by harming fisheries, tourism, and shipping, leading to economic losses, health problems, and disruptions to coastal communities (Fig. 5.6). The accumulation of marine litter disrupts these vital industries in several ways:

5.5.1. Fishing industry

Marine debris, particularly plastic waste, entangles fishing gear, damages nets, and reduces the catch rate, which directly impacts fishers' income. Polluted areas become less attractive for fishing, forcing fishermen to relocate or reduce their fishing activities, which reduces their income. Additionally, the loss of biodiversity and fish stocks, driven by habitat degradation and pollution, limits fishing opportunities and threatens long-term sustainability. As fish populations decrease, smaller catches lead to reduced revenue for local fishers and their families, further aggravating economic instability in fishing-dependent communities (Apete et al., 2024).

5.5.2. Aquaculture and mariculture

Marine litter can impede the growth of shellfish, seaweed, and other marine organisms cultivated through aquaculture practices. Floating debris can damage cultivation equipment, while polluted waters degrade the quality of produce, leading to financial losses. In some cases, contamination from plastics and chemicals can harm the health of farmed marine species, causing a decline in production and loss of marketability (Iheanacho et al., 2023).

5.5.3. Shipping

Marine litter, particularly plastic debris, causes economic losses in shipping through navigational hazards, entanglement of propellers and rudders, and damage to cooling systems, leading to operational downtime, repair costs, and potential injuries.

5.5.4. Coastal tourism

The appeal of pristine beaches and vibrant marine environments is crucial for attracting tourists to coastal areas. However, marine litter reduces the aesthetic value of beaches, creates a negative perception of a coastal area, and diminishes the quality of experiences for tourists, leading to a decline in tourism revenue. Additionally, the presence of litter can create safety hazards for beachgoers and disrupt recreational activities such as swimming, diving, and fishing, which are vital to local economies (Chen et al., 2021).

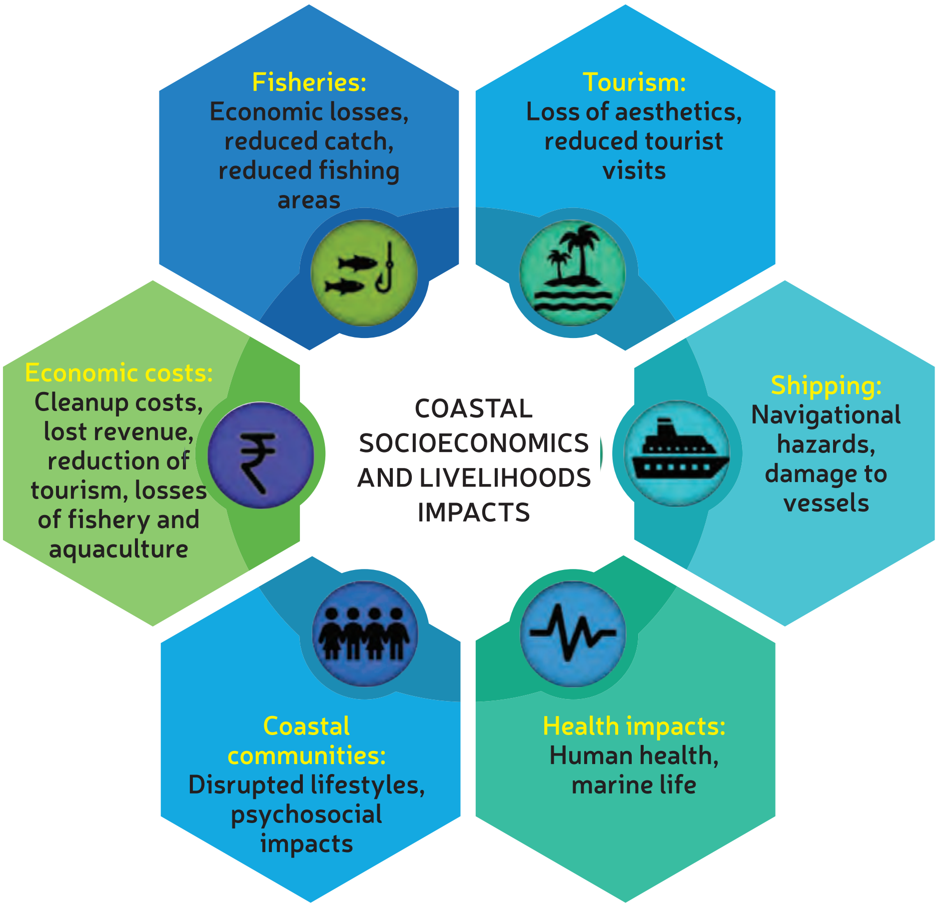


Fig.5.6: Marine pollution and its socioeconomic consequences

5.5.5. Coastal communities

Marine litter can disrupt the livelihoods and social structures of coastal communities, impacting their ability to fish, farm, or engage in other traditional activities. The inability to rely on marine resources for sustenance and income can lead to frustration, resentment, and a diminished sense of well-being.

5.5.6. Health impacts

Marine pollution can lead to health problems, including those caused by consuming contaminated seafood or exposure to pollutants released from plastic waste. Marine animals ingest plastic, become entangled, or are poisoned by chemicals released from litter, leading to injury, illness, and death.

5.5.7. Economic costs

The cost of removing marine litter can be substantial, placing a burden on local governments and taxpayers. The combined economic losses from reduced tourism, fisheries, and shipping can have a significant impact on coastal economies.

5.5.8. Cultural services and well-being

Coastal communities often have strong cultural connections to the ocean, with traditions such as fishing, boating, and coastal recreation forming an integral part of their identity and way of life. The degradation of coastal and marine ecosystems through pollution not only affects economic livelihoods but also diminishes cultural values and traditions, leading to a loss of sense of community and well-being. This is particularly evident in indigenous and rural coastal populations, where marine resources are intertwined with daily life (Yose et al., 2023).

Managing marine litter requires the development and implementation of waste management strategies and technologies, which can create job opportunities and stimulate economic growth in the waste management sector (Dijkstra et al., 2022).

6

BEACH LITTER: A KEY COMPONENT OF MARINE POLLUTION

6. BEACH LITTER: A KEY COMPONENT OF MARINE POLLUTION

Beach litter, the debris deposited along shorelines, is one of the most visible and harmful components of marine litter. It directly affects ecosystems, coastal aesthetics, and local livelihoods. Despite regularclean-up efforts, debris from both land-based and ocean-based sources continues to accumulate. Systematic surveys and mitigation efforts are essential to ensure clean, safe, and sustainable coastal environments (Cesarano et al., 2021).

WHY FOCUS ON BEACH LITTER?

Beaches act as natural deposition zones for marine litter, where debris accumulates due to tidal action, wave dynamics, wind transport, and direct human activities such as fishing, recreational beach use and unregulated dumping along the coast. These characteristics make beaches critical areas for monitoring and intervention. Trash, especially plastic, can travel long distances via ocean currents, impacting marine life far beyond its original source. Such debris can harm animals through ingestion or entanglement and contribute to widespread ocean pollution. The accumulation of litter on beaches affects:

1. Ecosystems: Harmful materials disrupt coastal habitats, affecting flora and fauna.
2. Availability of healthier marine produce: An unclean ocean can offer only contaminated seafood, leading to unsafe consumption and poor health metrics.
3. Local economies: Tourism and fisheries suffer due to degraded beach environments.

Fig. 6.1: The essential role of clean beaches: marine animal protection, safer seafood, and economic growth

4. Public health: Sharp objects, hazardous chemicals, and microplastics pose risks to human health (Sozio et al., 2024) (Fig. 6.1).

6.1. Beach litter surveys: a crucial stepin addressing marine litter

Beach litter is one of the most visible and problematic components of marine litter, posing threats to marine ecosystems, human health, and local economies. Debris accumulated on beaches not only destroys the aesthetic value of coastal environments but also causes far-reaching ecological and economic impacts. Given the role of beaches as focal points for debris accumulation, conducting systematic surveys of beach litter is essential to better understand the broader dynamics of marine pollution and to develop targeted mitigation strategies (Cesarano et al., 2023).

6.1.1. Importance of beach litter surveys

Beach litter surveys are essential tools for addressing the growing challenge of marine litter. These surveys generate both quantitative and qualitative data, forming the basis of understanding the extent and nature of the problem and finding informed targeted solutions. A primary objective of beach litter surveys is environmental impact assessment. By identifying harmful debris types, such as plastics and fishing gear, surveys reveal the risks posed to marine organisms through ingestion, entanglement, or habitat destruction (Slimane et al., 2025). They also help assess the long-term effects of debris on beach ecosystems and sediment quality (Mghili et al., 2024). Additionally, surveys play a crucial role in identifying the pollution sources. Analyzing the composition of litter allows researchers to trace its origins whether from local urban centers, fisheries, or maritime activities and distinguish between land-based and ocean-based pollution (Zielinski et al., 2019).

The data collected from the surveys serve as a foundation for policy formulation and implementation. Evidence-based insights inform waste management strategies, recycling initiatives, and anti-pollution regulations at local, national, and international levels. Furthermore, surveys enable monitoring and trend analysis by tracking the effectiveness of clean-up campaigns and waste reduction measures over time, while establishing baseline data to evaluate the success of mitigation efforts. Public engagement and awareness are also significant outcomes of beach litter surveys. By highlighting the impact of marine litter, these surveys inspire community participation in clean-up drives and promote sustainable practices, such as reducing single-use plastics and adopting eco-friendly habits. On a scientific front, the data gathered contribute to understanding debris movement, accumulation, and degradation processes, including the generation of microplastics and their environmental implications (Bettencourt et al., 2023). Beach litter surveys, therefore, are not only vital for maintaining cleaner coastlines but also for protecting marine biodiversity, improving coastal economies, and advancing global efforts to combat marine pollution (Mutuku et al., 2022).

6.1.2. Critical factors influencing beach litter accumulation

The type and quantity of litter that accumulates on beaches are influenced by a variety of interrelated factors. One key determinant is urban proximity. Beaches located near cities and towns tend to experience higher levels of litter due to greater human activity, including tourism, recreational use, and improper waste disposal. Oceanographic factors also play a crucial role in litter distribution (Kaviarasan et al., 2022). Ocean currents, wind patterns, and tidal flows transport debris from distant sources, depositing it along coastlines. These natural forces can make certain areas as litter hotspots (Honorato-Zimmer et al., 2019). The coastal morphology of a beach, including its slope, shape, and sediment composition, significantly influences how litter is retained or washed away. Beaches with gentle slopes and fine sediments are more likely to trap debris, while steeper beaches with coarse sands may experience less accumulation (Marin et al., 2019). Fishing and maritime activities contribute substantially to beach litter. The proximity of fishing zones, shipping lanes, and ports increases the likelihood of ALDFG and other maritime debris ending up on shorelines. Additionally, riverine inputs are a major source of beach litter (Parga-Martínez et al., 2020). Rivers act as conduits, carrying large quantities of land-based waste from urban, industrial, and agricultural areas directly into the marine environment, where it eventually washes ashore (Rech et al., 2014) (Fig. 6.2). Understanding these factors is essential for designing effective strategies to manage and mitigate beach litter, as it allows for targeted interventions that address both the sources and pathways of marine debris.

6.1.3. Challenges in beach litter management

Managing beach litter effectively is a complex task that requires addressing several interconnected challenges. One major issue is the limited resources for clean-up. Many coastal areas lack the necessary infrastructure, workforce, and funding to conduct regular large-scale beach cleanup operations, leaving litter to accumulate over time (Rangel-Buitrago et al., 2018). Litter on beaches comes from various sources like land-based waste, storm drains, river systems, and recreational activities, making it difficult to pinpoint and address the root causes (Fig. 6.3).

Another significant challenge is insufficient

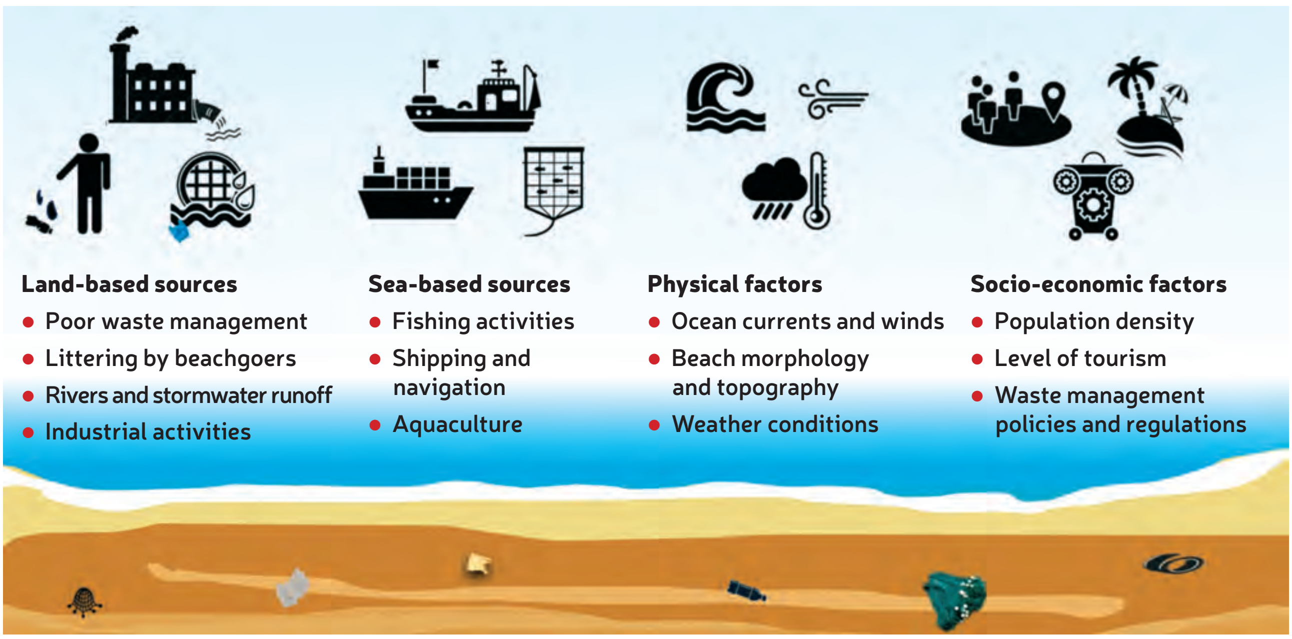


Fig. 6.2: Key drivers of beach litter

Fig. 6.3: Key challenges in effective beach litter management: A multi-faceted perspective

public awareness. Many individuals remain unaware of the detrimental impacts of litter on marine ecosystems, coastal economies, and public health. This lack of awareness often results in improper waste disposal and minimal community participation in mitigation efforts (Mugilarasan et al., 2021). Tide changes and weather events can constantly move and redistribute litter along the coastline, making clean-up efforts inconsistent. Transboundary pollution further complicates the management of beach litter. Marine debris originating from other regions, carried by ocean currents, makes it difficult to control litter at a local level and requires international collaboration for effective mitigation (Prevenios et al., 2018). Additionally, weak regulatory enforcement undermines existing policies and efforts to prevent littering. While many regions have regulations in place, the lack of enforcement mechanisms and penalties often allows littering to remain unchecked for long (Mugilarasan et al., 2023). Addressing these challenges requires a combination of stronger policy enforcement, increased public education, enhanced international cooperation, and investment in sustainable clean-up and waste management infrastructure. Only by overcoming these hurdles can effective and long-term solutions to beach litter be achieved.

6.1.4. Methods and tools for conducting surveys

To ensure accuracy and consistency in data collection, standardized methodologies and tools are employed in beach litter surveys (Lippiatt et al., 2013; GESAMP, 2019).

6.1.4.1. Methodologies for data collection

- **Transect line method:** Surveyors mark transects perpendicular to the shoreline, typically covering a fixed width of the beach. Litter is recorded within these transects to quantify debris density.

- **Quadrat sampling:** Defined sections (quadrats) of the beach are analyzed for litter types and abundance. This method is useful for understanding spatial distribution.

- **Stratified sampling:** Beaches are divided into zones based on usage (tourist areas, fishing zones) or characteristics (tidal influence, proximity to urban areas).

- **Citizen science approaches:** Engaging local communities and volunteers in beach litter surveys increases the scope and awareness of the issue while generating valuable data.

6.1.4.2. Tools and instruments

- **GPS devices:** For precise geo-tagging of survey locations.

- **Data sheets:** Standardized forms for Marine debris to record litter data.

- **Weighing scales:** To measure the weight of collected litter.

- **Litter categorization manuals:** Standard guides (e.g., UNEP/IOC's Guidelines on Survey and Monitoring of Marine Litter) to classify debris types.

- **Handheld magnifiers or microscopes:** For identifying microplastics and smaller debris.

- **Drones and remote sensing tools:** To assess inaccessible areas or conduct large-scale surveys efficiently.

In the current research, systematic methodologies were employed to collect and analyse beach litter data along the coastline of Tamil Nadu. The Transect Line Method was used, where geo-tagged transects were established perpendicular to the shoreline to ensure systematic data collection. This method facilitated the assessment of litter density and distribution across various beach locations, allowing for consistent and comparable data.

Additionally, standardized data sheets, following NOAA's marine debris monitoring and assessment guidelines (Lippiatt et al., 2013), were used to record important details such as litter types, quantities, and other site-specific observations. This combination of techniques provided a scientifically robust approach to understanding beach litter, enabling detailed insights into its composition, sources, and potential environmental impacts.

7

BASELINE SURVEYS IN TAMIL NADU: A COMPREHENSIVE APPROACH

7. BASELINE SURVEYS IN TAMIL NADU: A COMPREHENSIVE APPROACH

7.1. Assessment of beach litter along the coast of Tamil Nadu

7.1.1. Background

Tamil Nadu, a prominent eastern coastal state of India, has a vast coastline stretching 1,068.69 km and accounting for approximately 15% of the country's total shoreline. This extensive coastal region hosts ecologically significant habitats, including coral reefs, seagrass meadows, and wetlands, which support a rich diversity of marine and coastal species. The coastline is a hub of various human activities such as fishing, shipping, tourism, and recreation, with a significant portion of the population dependent on fishing for their livelihood. However, the increasing accumulation of anthropogenic litter along Tamil Nadu's beaches poses a serious environmental and socioeconomic challenge.

Beaches in Tamil Nadu receive debris from multiple sources, including solid waste dumped near the shore, inland waste carried by rivers via estuaries to the sea, and extensive fishing activities. Seasonal monsoon-driven floods, storm surges, and coastal erosion further exacerbate litter deposition by mobilizing vast quantities of waste, particularly from landfills and areas prone to heavy littering (Sivadas et al., 2022). Agricultural runoff, domestic sewage, and industrial discharge also add to the load of coastal pollution. This results in the degradation of critical ecosystems. The high population density along the coast also intensifies pressure on natural resources, leading to increased waste generation and improper disposal practices.

Once deposited on beaches, litter may accumulate on the backshore or become buried depending on factors such as wave action, beach morphology, and sediment characteristics (Williams and Tudor, 2001). Among the various types of beach litter, plastic is the most dominant, as highlighted by multiple studies (Gaibor et al., 2020; Krishnakumar et al., 2020; Jeyasanta et al., 2020; Sulochanan et al., 2019; Kaladharan et

al., 2017). Plastics are widely used due to their affordability, lightweight, flexibility, and ease of disposal, which has contributed to their prevalence in marine debris. Tamil Nadu is responsible for approximately 18% of India's total plastic waste entering the ocean, with an estimated 1.7 million tons of plastic waste generated annually, of which around 108,000 tons are directly discharged into the marine environment through rivers and littering (TOI, 2018 and 2019).

Addressing the issue of beach litter requires a systematic assessment of its accumulation, sources, and composition. Quantifying litter density and distribution is essential for understanding pollution trends and implementing effective mitigation strategies. This study provides a comprehensive evaluation of beach litter across 52 coastal villages in 13 districts of Tamil Nadu. Specifically, it aims to:

- Assess the density and spatial distribution of beach litter pollution along Tamil Nadu's coastline
- Analyze the composition, sources, and impact of litter through detailed investigations

The findings of this study contribute to a broader understanding of the magnitude, extent, and impacts of marine litter in Tamil Nadu, providing valuable insights for policymakers, researchers, and stakeholders working towards sustainable coastal management and marine conservation.

The results from this study were published as Patterson Edward et al. (2025),"Assessment of beach litter, including Abandoned, Lost, or Discarded Fishing Gear (ALDFG), along the coast of Tamil Nadu, India: Magnitude, sources, composition, pollution status, and management strategies" in Marine Pollution Bulletin, 213(2025), 117700.

7.1.2. Study area

In this study, beaches in 52 fishing-dominant villages were selected for a beach litter survey across 13 districts of state, excluding the Gulf of Mannar (GOM). This omission was intentional, for a separate ALDFG assessment in GOM had already been conducted under the MARESSOL project, covering 12 fishing villages. The findings from that study have been published in the report 'Marine litter from fisheries in the Gulf of Mannar and Palk Strait: knowledge basis and recommended avenues for change' (MARESSOL, 2022). To avoid duplication, this study focused on new areas, and the map reflects the 52 surveyed villages (Fig.7.1). These beaches host a variety of major and minor industries, as well as fishing and recreational activities. These activities present significant threats to both the coastal environment and its biodiversity. Table 7.1 provides details of the beach litter survey sites, including location, district, geographic coordinates, and transect lengths.

7.1.3. Shoreline debris survey methods and classification framework

To assess shoreline debris accumulation and potential sources, the NOAA Marine Debris Program's standing-stock survey methodwas adopted (Lippiatt et al., 2013).This standardized method quantifies visible debris that has accumulated over time, unaffected by recent clean-ups, thus providing robust input for temporal comparisons and impact assessments. The surveys in the 52 fishing villages were conducted between January and June 2024. Sites were selected based on four criteria:direct exposure to open sea, ease of access for field teams, lack of recent clean-up activities, and suitability for consistent sampling.

At each location, four transects (5 m wide × 100 m long) were randomly placed along the high tide line, covering 20% of each beach stretch(Fig.7.2). All items of debris ⩾0.5 cm were collected from the high tide mark to the inland vegetation line. Items were sorted by trained personnel, counted, and weighed using calibrated portable scales.

Litter classification followed UNEP guidelines, categorizing debris into three primary groups: plastics, non-plastics, and ALDFG (GESAMP, 2019). Only plastics explicitly linked to fisheries, such as nets, floats, and lines, were classified

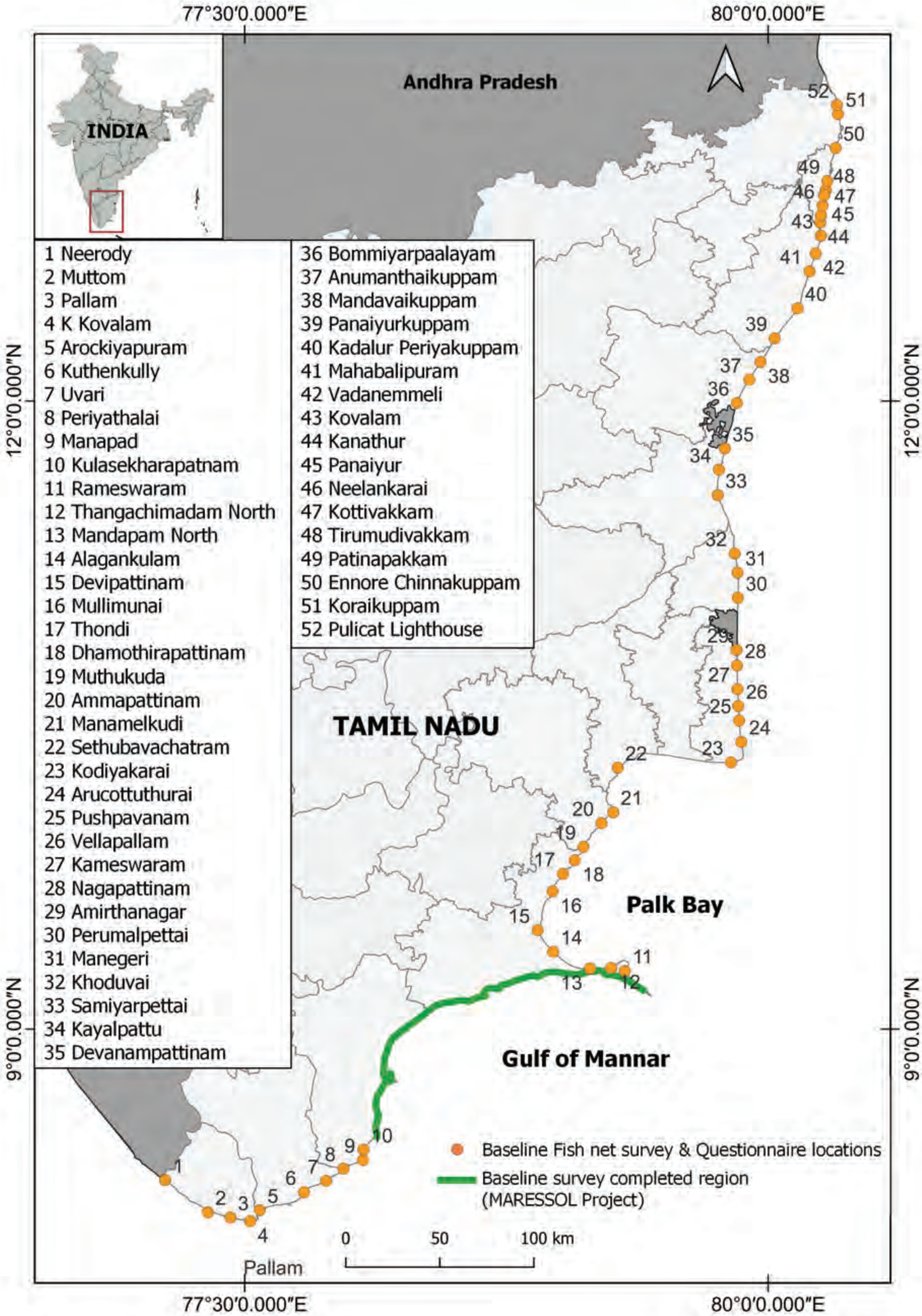


Fig.7.1: Map showing 52 fishing-dominant villages covering 13 coastal districts along the coast of Tamil Nadu for baseline survey and assessment

Table 7.1. Beach litter survey - Site and transect details

S No	Name of the place	District	Latitude	Longitude	Transect length (m)			
1	Neerody	Kanniyakumari	8°17'21.00"N	77° 6'7.50"E	30	27	20.7	17.5
2	Muttom	Kanniyakumari	8° 7'24.42"N	77°19'25.74"E	18	14	14	17
3	Pallam	Kanniyakumari	8° 5'55.49"N	77°25'54.80"E	50	50	55	40
4	K Kovalam	Kanniyakumari	8° 4'52.24"N	77°31'34.72"E	16	15	24	30
5	Arockiyapuram	Kanniyakumari	8° 7'8.73"N	77°33'31.75"E	17	15	13	13
6	Kuthenkully	Tirunelveli	8°13'8.25"N	77°46'59.79"E	28	30	32	32
7	Uvari	Tirunelveli	8°16'25.42"N	77°53'18.44"E	14	13	11	12
8	Periyathalai	Tirunelveli	8°19'56.02"N	77°58'16.91"E	28	30	30	21
9	Manapad	Tuticorin	8°22'35.12"N	78° 3'34.42"E	19	13	24	15
10	Kulasekarapatnam	Tuticorin	8°23'36.16"N	78° 3'28.97"E	19	20	24	24
11	Rameswaram	Ramanathapuram	9°16'38.67"N	79°18'56.41"E	10	10.5	10.3	10.3
12	Thangachimadam North	Ramanathapuram	9°17'29.44"N	79°15'2.56"E	30	43	24	35
13	Mandapam North	Ramanathapuram	9°17'20.92"N	79° 8'56.93"E	14	15	15	10
14	Alagankulam	Ramanathapuram	9°22'10.81"N	78°58'24.16"E	30	30	30	30
15	Devipattinam	Ramanathapuram	9°28'20.43"N	78°53'58.58"E	17	14	13	14.3
16	Mullimunai	Ramanathapuram	9°39'28.67"N	78°58'15.30"E	28	28	29	24
17	Thondi	Ramanathapuram	9°44'29.26"N	79° 1'14.23"E	15	12	14	20
18	Dhamothirapattinam	Ramanathapuram	9°47'27.11"N	79° 4'4.77"E	18	11	13	12
19	Muthukuda	Pudukottai	9°52'14.00"N	79° 7'5.20"E	23	22	19	7
20	Ammapattinam	Pudukottai	10° 0'31.17"N	79°13'39.68"E	9	8	12	7
21	Manamelkudi	Pudukottai	10° 1'41.51"N	79°14'48.69"E	11.7	11.6	8.8	10
22	Sethubavachatram	Thanjavur	10°14'55.10"N	79°16'55.91"E	6	7.5	8	10
23	Kodiyakarai	Nagapattinam	10°16'28.04"N	79°49'23.30"E	17	27	27	18
24	Arucottuthurai	Nagapattinam	10°23'29.95"N	79°52'10.11"E	10.4	21	15	19
25	Pushpavanam	Nagapattinam	10°27'5.91"N	79°51'50.01"E	30	30	30	30
26	Vellapallam	Nagapattinam	10°31'12.02"N	79°51'41.44"E	38	35	35	35
27	Kameswaram	Nagapattinam	10°37'26.65"N	79°51'16.38"E	30	25	35	35
28	Nagapattinam	Nagapattinam	10°46'47.08"N	79°51'2.64"E	40	42	45	45
29	Amirthanagar	Nagapattinam	10°47'53.98"N	79°51'2.56"E	20	25	19	5
30	Perumalpettai	Mayladudurai	11° 3'31.36"N	79°51'20.67"E	17	20	20	25
31	Manegeri	Mayladudurai	11° 7'46.60"N	79°51'28.27"E	35	30	30	30
32	Khoduvai	Mayladudurai	11°16'14.05"N	79°50'26.53"E	35	35	35	38
33	Samiyarpettai	Cuddalore	11°32'57.86"N	79°45'35.99"E	38	35	35	35
34	Kayalpattu	Cuddalore	11°41'14.39"N	79°46'26.22"E	40	40	40	40
35	Devanampattinam	Cuddalore	11°44'23.76"N	79°47'13.26"E	35	35	35	35
36	Bommiyarpaalayam	Villupuram	11°59'24.36"N	79°51'4.16"E	25	25	20	10
37	Anumanthaikuppam	Villupuram	12° 7'11.47"N	79°55'14.95"E	35	35	35	35
38	Mandavaikuppam	Villupuram	12° 9'42.24"N	79°56'51.51"E	30	30	30	30
39	Panaiyurkuppam	Chengalpattu	12°17'58.03"N	80° 1'54.24"E	28	24	25	35
40	KadalurPeriyakuppam	Chengalpattu	12°26'34.47"N	80° 8'27.48"E	23	27	24	30
41	Mahabalipuram	Chengalpattu	12°37'12.45"N	80°11'54.17"E	16	13	13	13
42	Vadanemmeli	Chengalpattu	12°42'18.18"N	80°13'40.35"E	27	30	18	30
43	Kovalam	Chengalpattu	12°47'25.64"N	80°15'9.88"E	18	23	13	19
44	Kanathur	Chennai	12°51'11.38"N	80°14'56.23"E	10	5	5	5
45	Panaiyur	Chennai	12°53'16.73"N	80°15'9.76"E	12	11	12	8
46	Neelankarai	Chennai	12°57'13.77"N	80°15'44.90"E	12	13	13	30
47	Kottivakkam	Chennai	12°58'0.93"N	80°15'54.08"E	15	12	15	10
48	Tirumudivakkam	Chennai	12°59'4.64"N	80°16'8.87"E	30	20	30	35
49	Patinapakkam	Chennai	13° 1'17.65"N	80°16'42.52"E	50	40	40	40
50	EnnoreChinnakuppam	Chennai	13°12'32.29"N	80°19'22.93"E	17	20	20	24
51	Koraikuppam	Thiruvallur	13°22'54.56"N	80°20'0.92"E	40	35	35	35
52	Pulicat Lighthouse	Thiruvallur	13°24'53.58"N	80°19'43.45"E	40	40	35	40

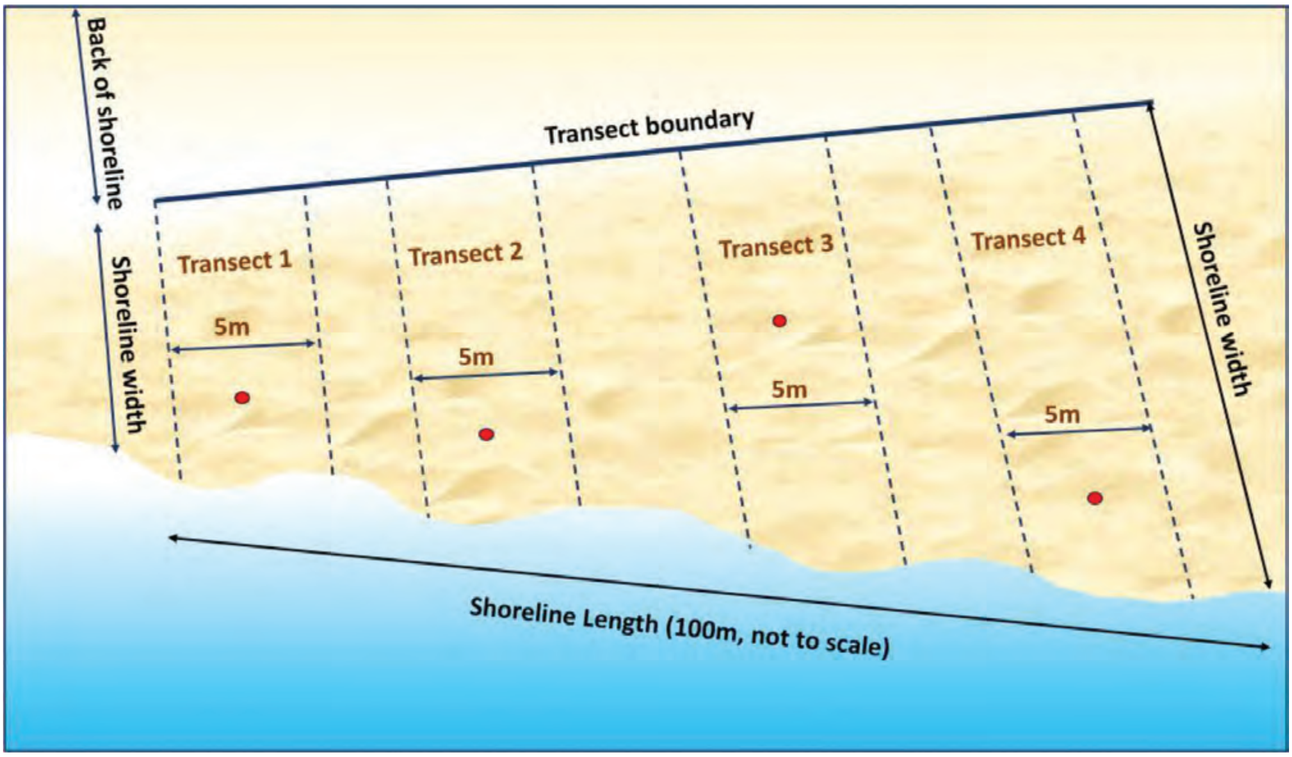


Fig.7.2: Shoreline debris assessment site

as ALDFG, based on methodologies outlined in previous studies (Richardson et al., 2019). Size classification followed standard definitions: mesoplastics (0.5-2.5 cm), macroplastics (2.5-100 cm), and megaplastics (>100 cm). Source categorization of items was guided by the European Marine Observation and Data Network (EMODnet, 2023) protocol, attributing probable origins such as fisheries, tourism, or household waste based on morphology, material type, and site characteristics. Oversized debris unsuitable for transport was recorded separately but not weighed.

7.1.4. Assessment of coastal solid waste dumping sites for marine litter

The indiscriminate dumping of waste along shorelines poses severe threats to marine ecosystems and biodiversity. To assess the extent of coastal solid waste disposal, a handheld GPS device was used to map and document dumping sites near the shore. These sites received both household waste and discarded fishing gear. Larger debris items were identified and recorded through direct observation, and each site was photographed with GPS tagging for further analysis (MARESSOL, 2022).

7.1.5. Quantification of marine litter data

To determine the dry weight (DW) of collected marine litter, all plastic items gathered from the 52 surveyed sites were carefully rinsed with freshwater in the laboratory. This process removed attached sand, shells, biofilm, and other contaminants. The cleaned plastic items were then air-dried for 24 hours to eliminate residual moisture before weighing.

The concentration of marine litter (items/m^2) per transect was calculated using the formula of Lippiatt et al. (2013):

$$C = \frac{n}{w \times l}$$

Where:

- C = Concentration of marine debris (items/m^2)
- n = Total number of debris items per transect
- w = Width (m) of the sampled shoreline section (transect width)
- l = Length (m) of the shoreline sampled, set at 5 m

To estimate the total quantity of beach litter, the calculated concentration was multiplied by the total beach area of each village. The beach area was determined by multiplying the coastline length by the mean beach width (Kaladharan et al., 2017).

7.1.6. Polymer identification

A representative subsample of 3,850 plastic litter items, randomly selected from all surveyed beaches, was analyzed for polymer composition. After thorough cleaning, plastic items measuring at least 3 cm (or 3 cm in length for fibrous materials) were stored in paper bags for further analysis. In the laboratory, any remaining organic residues were removed, and the plastic and ALDFG items were further cleaned using ultrapure water and 96% ethanol before spectroscopic examination.

Polymer identification was conducted using Attenuated Total Reflection-Fourier Transform Infrared Spectroscopy (ATR-FTIR) with a Nicolet iS10 FTIR Spectrometer. Spectral data were obtained from 32 co-scans within a wave number range of 675-4000 cm^{-1} at a resolution of 4 cm^{-1}. The resulting spectra were compared against reference spectra from the Hummel Polymer Library and the Center for Marine Debris Research. A spectral match was considered valid if the similarity score exceeded 70%, and all matches were further verified by the instrument user. For each analyzed subsample, the identified polymer type and matching accuracy were documented.

7.1.7. Data analysis

Marine debris concentrations were expressed as mean values ± standard deviation (SD). A one-way analysis of variance (ANOVA) was performed to assess variations in plastic debris, fishing-related debris (ALDFG), and non-plastic litter across surveyed beaches. Data normality was tested prior to analysis, and Tukey's Post Hoc test was applied for multiple mean comparisons. The density of marine debris was calculated as items/m^2 ± SD, with statistical significance set at $p < 0.05$. To explore patterns and correlations within the dataset, Principal Component Analysis (PCA) was employed to identify key factor groupings and qualitative variance across sites. Additionally, Hierarchical Cluster Analysis (HCA) was conducted using Ward's method with a Bray-Curtis similarity matrix to determine relationships among variables and visualize clustering patterns in a dendrogram. All statistical analyses were performed using PAST software version 3.25.

7.2. Findings and Interpretation

7.2.1. Abundance and distribution of beach litter

The marine debris assessment methodology of National Oceanic and Atmospheric Administration (NOAA) employs standing-stock surveys to monitor debris accumulation on shorelines over time. These surveys provide quantitative snapshots of debris levels, enabling cumulative impact assessments and risk evaluations at local and regional scales. In this study, a total of 6,132 marine debris items weighing 201 kg were recorded along a 1,040-meter surveyed shoreline (20 meters per village) across 52 coastal villages in 13 districts of Tamil Nadu. The debris composition included 2,915 items (93 kg) of ALDFG, 2,426 items (58 kg) of plastic debris, and 791 items (51 kg) of non-plastic debris (Fig.7.3). Plastic litter was the predominant debris type, attributed to its high persistence, slow decomposition rate, and continuous input from both land- and sea-based sources (Mishra et al., 2023). ALDFG accounted for 47.5% of total debris items and 46% of total litter weight (Fig. 2), aligning with global patterns of ALDFG prevalence of, for example, 62% in Vietnam (Fruergaard et al., 2022), 45% in the Arabian Sea (Kaviarasan et al., 2020), and 46% in the Great Pacific Garbage Patch (Lebreton et al., 2018).

The density of marine debris across the 52 surveyed sites ranged from 0.18 to 6.3 items/m^2, with an average of 1.14 items/m^2 by number and 0.05 kg/m^2 by weight. This is consistent with reports from other coastal regions, such as Ecuador (1.13 items/m^2) (Gaibor et al., 2020) and Gujarat, India (1.14 items/m^2) (Behera et al., 2021). Among the 13 surveyed districts, the highest litter con-

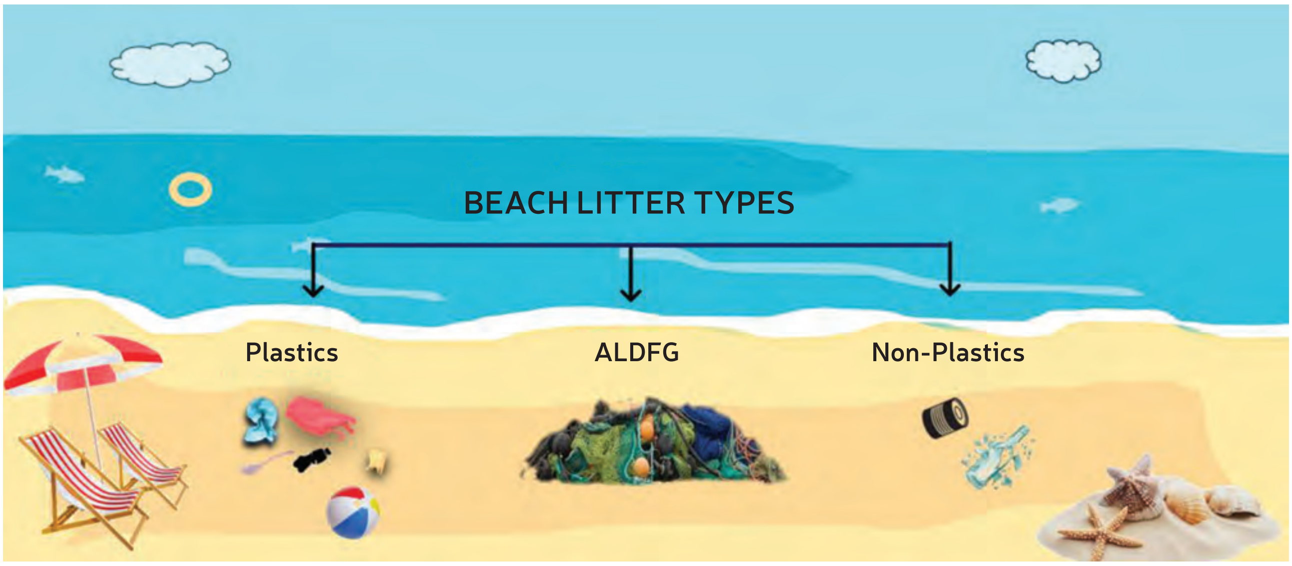


Fig.7.3: Classification of beach litter: Plastics, ALDFG, and Non-Plastics

centrations were recorded in Pudukottai (2.68 items/m^2, 0.20 kg/m^2) and Villupuram (2.04 items/m^2, 0.09 kg/m^2) (Fig. 7.4). These elevated concentrations, likely linked to intensive fishing-related activities, are consistent with the data of previous studies identifying commercial fishing as a major contributor to marine debris (Edyyane et al., 2004; Unger & Harrison, 2016).

A study in the Mediterranean region (Haseler et al., 2025) reported higher macro litter densities (1.71 items/m^2), with urban beaches (2.63 items/m^2) and tourist beaches (1.23 items/m^2) exhibiting particularly high litter loads. Meso litter densities in urban areas were even greater, reaching 9.91 items/m^2. While fishing-related activities were the primary source of marine lit-

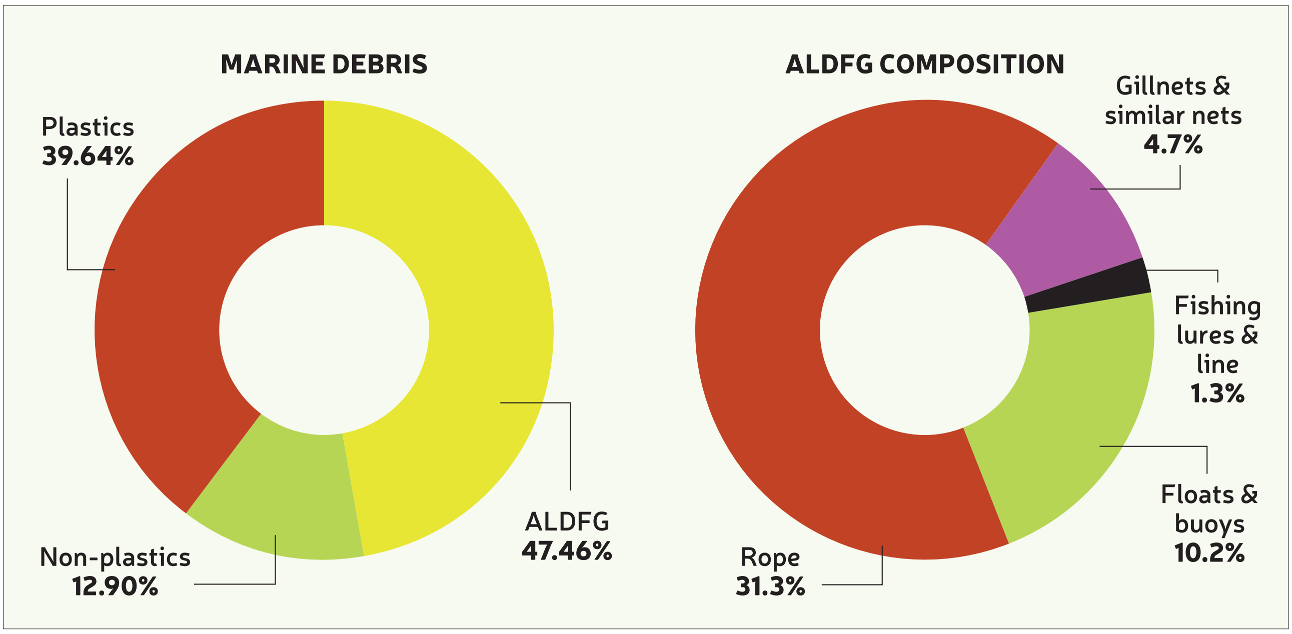


Fig.7.4: Overall composition (%) of beach litter in Tamil Nadu coast

Table 7.2. Overall concentration of beach litter (no of items/m²) and weight (kg/m²) in Tamil Nadu coast

Fishing villages	No. of items/m²	Weight (kg/m²)
Neerody	1.09 ± 0.27	0.02 ± 0.001
Muttom	1.41 ± 0.88	0.08 ± 0.002
Pallam	1.94 ± 0.65	0.01 ± 0.001
K Kovalam	0.47 ± 0.22	0.01 ± 0.005
Arockiyapuram	2.12 ± 0.25	0.02 ± 0.001
Periyathalai	0.97 ± 0.33	0.02 ± 0.001
Uvari	1.08 ± 0.57	0.03 ± 0.001
Kuthenkully	1.48 ± 0.47	0.04 ± 0.002
Kulasekarapattinam	0.44 ± 0.27	0.02 ± 0.004
Manapad	2.33 ± 0.87	0.01 ± 0.001
Rameswaram	0.70 ± 0.05	0.05 ± 0.002
Thangachimadam North	2.53 ± 0.97	0.11 ± 0.003
Mandapam North	1.92 ± 0.87	0.06 ± 0.005
Alagankulam	1.46 ± 0.14	0.04 ± 0.002
Devipattinam	2.71 ± 0.97	0.07 ± 0.006
Mullimunai	0.73 ± 0.11	0.03 ± 0.001
Thondi	1.82 ± 0.58	0.08 ± 0.002
Dhamothirapattinam	0.50 ± 0.21	0.05 ± 0.002
Muthukuda	0.90 ± 0.37	0.08 ± 0.004
Ammapattinam	6.30 ± 1.24	0.15 ± 0.007
Manamelkudi	0.86 ± 0.24	0.07 ± 0.001
Sethubavachatram	1.60 ± 0.67	0.20±0.002
Kodiyakarai	1.04 ± 0.98	0.02 ± 0.001
Arucottuthurai	0.55 ± 0.24	0.05 ± 0.004
Pushpavanam	0.42 ± 0.21	0.02 ± 0.002
Vellapallam	0.33 ± 0.08	0.01 ± 0.001

Fishing villages	No. of items/m²	Weight (kg/m²)
Kameswaram	0.21 ± 0.11	0.01 ± 0.001
Nagapattinam	0.34 ± 0.08	0.01 ± 0.003
Amirthanagar	1.02 ± 0.54	0.04 ± 0.002
Perumalpettai	0.34 ± 0.07	0.01 ± 0.001
Manegeri	0.33 ± 0.04	0.03 ± 0.002
Khoduvai	0.25 ± 0.07	0.01±0.003
Samiyarpettai	0.26 ± 0.05	0.02 ± 0.001
Kayalpattu	0.18 ± 0.09	0.02 ± 0.002
Devanampattinam	0.47 ± 0.07	0.04 ± 0.002
Mandavaikuppam	0.61 ± 0.01	0.05 ± 0.001
Bommiyaroalayam	1.72 ± 0.09	0.06 ± 0.001
Anumanthaikuppam	3.80 ± 1.25	0.02 ± 0.001
Panaiyurkuppam	0.39 ± 0.08	0.02 ± 0.001
KadalurPeriyakuppam	0.43 ± 0.09	0.01 ± 0.001
Mahabalipuram	0.67 ± 0.04	0.05 ± 0.002
Vadanemmeli	0.52 ± 0.07	0.02 ± 0.001
Kovalam	0.65 ± 0.05	0.08 ± 0.002
Kanathur	3.09 ± 1.05	0.07 ± 0.003
Panaiyur	0.56 ± 0.04	0.05 ± 0.002
Neelankarai	1.10 ± 0.22	0.06 ± 0.001
Kottivakkam	1.08 ± 0.45	0.04 ± 0.002
Tirumudivakkam	0.85 ± 0.03	0.04 ± 0.001
Patinapakkam	1.20 ± 0.24	0.06 ± 0.002
EnnoreChinnakuppam	0.78 ± 0.29	0.06 ± 0.004
Koraikuppam	0.45 ± 0.08	0.04 ± 0.002
Pulicat lighthouse	0.44 ± 0.07	0.01 ± 0.001

ter, the Mediterranean study identified shoreline activities and inadequate waste management as dominant factors. Despite these differences, both studies underscore the urgent need for targeted waste management interventions, particularly in high-risk coastal zones, to mitigate the impact of marine litter effectively.

Environmental and anthropogenic factors play a significant role in shaping marine litter distribution patterns along the Tamil Nadu coastline. Among these, fishing activity emerged as a primary driver, with villages such as Ammapattinam (Pudukottai) and Anumanthaikuppam (Villupuram) recording the highest ALDFG densities (Table 7.2). These findings align with the data of previous studies that identified fishing zones as marine debris hotspots, primarily due to the accidental loss of fishing gear and improper disposal practices. Additionally, factors such as seasonality, beach morphology, and proximity to river inlets contributed to the variability in debris accumulation. Beaches located near river mouths or with inadequate waste management systems exhibited higher litter loads due to runoff and insufficient disposal facilities (Kaviarasan et al., 2022).

Statistical analyses further supported these findings. ANOVA revealed significant differences in plastic litter concentrations across the surveyed sites ($p = 0.004$ at the 0.05 significance level),

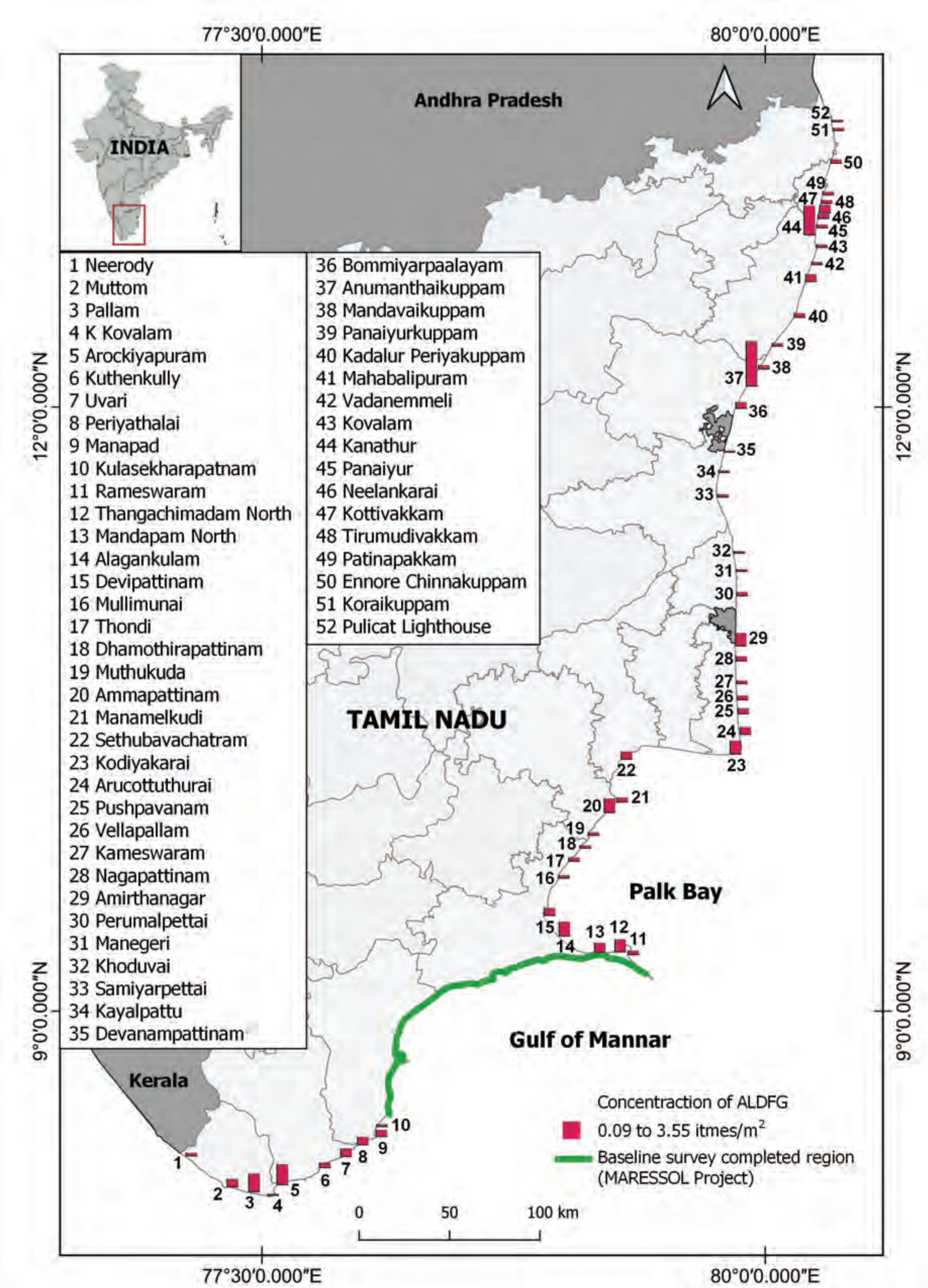


Fig. 7.5: Site-wise concentration of ALDFG litter (no/m^2) in Tamil Nadu coast

confirming spatial variability in debris distribution. The highest densities of ALDFG were found in Villupuram (1.43 items/m^2), which is characterized by intensive fishing activities. Conversely, Cuddalore exhibited lower debris concentrations (Fig. 7.5), suggesting that factors such as reduced fishing operations, improved waste management, or fewer visitors may contribute to decreased litter accumulation. A post-hoc Tukey's test ($p < 0.05$) further confirmed significant variations in ALDFG concentrations across sites, reinforcing the link between intensive fishing activity and higher debris loads, which include both fishing-related waste and general litter.

A comparative analysis of total estimated marine debris across the 52 surveyed villages indicated that Ammapattinam and Anumanthaikuppam had the highest debris estimates, at 25,210 and 24,140 items, respectively (Table 7.3). These results provide direct evidence of the impact of fishing-related activities on shoreline litter loads. A post-hoc Tukey's test ($p < 0.05$) reaffirmed that sites with intensive fishing operations exhibited significantly higher debris concentrations, highlighting the need for localized interventions to address both fishing-related and general waste management challenges.

From a coastal pollution management perspective, these findings underscore the urgent need for enhanced waste management strategies to mitigate the impact of ALDFG and other marine debris. Implementing gear retrieval programs, improving waste disposal infrastructure, and enforcing stricter regulations on fishing gear disposal would be crucial steps toward reducing ALDFG accumulation. Additionally, sustainable fishing practices and community-driven waste management initiatives could help curb the influx of marine litter. The study provides critical insights into litter distribution along Tamil Nadu's coastline, emphasizing that marine debris is not only driven by fishing activities but also influenced by broader environmental factors. A deeper understanding of these drivers can inform targeted pollution mitigation strategies, ultimately reducing the negative impacts of marine litter on coastal ecosystems and local communities.

7.2.2. Relationship of litter abundances among the three size classes

Based on their size, litter items (plastic, ALDFG, and non-plastic) were classified as mesoplastic (0.5-2.5 cm), macroplastic (2.5-100 cm), and megaplastic (>100cm). The mean length of all beached litter sampled was 20 ± 9.25 cm, ranging from 2 to 1000 cm. Plastic items (20.5%) and non-plastic litter items (11%) were most abundant in macro size class, whereas fishing-related ALDFG litter was predominantly observed in the mega size class (28%) (Fig.7.6). This was largely due to large items such as fishing nets (286 items averaging 65.8 ± 32.8 cm in length and 43.54 ± 24 g in weight) and fishing ropes (189 items averaging 55.3 ± 33.7 cm in length and 42.2 ± 33 g in weight), which are heavy, durable and persistent in the marine environment.

Small-sized debris, such as mesoplastics, consists of fragments measuring between 2 to 5 cm, commonly referred to as meso-particles or meso-debris. These smaller debris types are often buried beneath the surface, making them less visible and more challenging to collect compared to larger pieces of debris, known as macro-debris. As a result, meso-debris frequently goes unnoticed in clean-up operations, posing ongoing challenges to environmental management and marine conservation efforts. Moreover, mesoplastics also originate from net preparation processes in the form of small fragments of net and rope. During routine net cleaning and repair, numerous small plastic pieces are generated and released into the environment. However, this source of pollution is often overlooked, despite its significant contribution to beach litter and eventual entry into the marine ecosystem. While policies and mitigation efforts frequently focus on macro- and micro-debris, it is crucial that policymakers also address meso-debris, given its continuous generation and accumulation in coastal and marine environments. The distribution of litter is influenced by environmental and anthropogenic factors. The prevalence of megaplastic ALDFG is linked to intensive fishing

Table 7.3. The estimated amount of beach debris based on shoreline survey

Fishing villages	No. of items/m²	Weight kg/m²	Total beach area (m²)	Estimated quantity of beach debris in total beach area	
				No. of items	kg of debris
Neerody	1.09	0.02	3000	3270.60	70.35
Muttom	1.41	0.08	10000	14115.78	780.44
Pallam	1.94	0.01	9000	17464.91	131.61
K Kovalam	0.47	0.01	5500	2590.73	73.64
Arockiyapuram	2.12	0.02	5000	10616.14	96.66
Periyathalai	0.97	0.02	10000	9664.29	178.88
Uvari	1.08	0.03	3500	3769.27	107.37
Kuthenkully	1.48	0.04	5000	7383.63	215.31
Kulasekarapattinam	0.44	0.02	5500	2444.48	104.14
Manapad	2.33	0.01	6000	13960.69	75.98
Rameswaram	0.70	0.05	10000	7007.81	492.97
Thangachimadam North	2.53	0.11	6000	15167.69	655.55
Mandapam North	1.92	0.06	10000	19169.05	633.62
Alagankulam	1.46	0.04	6000	8760.00	237.14
Devipattinam	2.71	0.07	4500	12180.68	310.41
Mullimunai	0.73	0.03	5000	3627.36	171.37
Thondi	1.82	0.08	4000	7281.90	312.87
Dhamothirapattinam	0.50	0.05	2500	1254.37	122.63
Muthukuda	0.90	0.08	4000	3599.58	334.78
Ammapattinam	6.30	0.15	4000	25210.32	584.42
Manamelkudi	0.86	0.07	3500	3010.14	237.87
Sethubavachatram	1.60	0.20	2500	3996.88	509.91
Kodiyakarai	1.04	0.02	9500	9909.29	237.49
Arucottuthurai	0.55	0.05	8000	4403.54	417.10
Pushpavanam	0.42	0.02	13000	5438.33	200.20
Vellapallam	0.33	0.01	10000	3269.17	92.94
Kameswaram	0.21	0.01	10000	2125.71	90.20
Nagapattinam	0.34	0.01	9000	3023.21	82.30
Amirthanagar	1.02	0.04	8000	8160.63	310.65
Perumalpettai	0.34	0.01	7000	2389.06	80.90
Manegeri	0.33	0.03	6000	1972.86	184.51
Khoduvai	0.25	0.01	9500	2406.07	54.01
Samiyarpettai	0.26	0.00	8000	2045.11	33.59
Kayalpattu	0.18	0.00	9000	1620.00	37.49
Devanampattinam	0.47	0.01	5000	2342.86	66.74
Mandavaikuppam	0.61	0.02	4500	2737.50	72.66
Bommiyaroalayam	1.72	0.06	6800	11699.40	429.86
Anumanthaikuppam	3.80	0.02	6500	24718.57	123.91
Panaiyurkuppam	0.39	0.02	7000	2757.58	142.90
KadalurPeriyakuppam	0.43	0.01	3500	1520.15	35.88
Mahabalipuram	0.67	0.05	6500	4348.44	337.13
Vadanemmeli	0.52	0.02	5000	2607.41	109.37
Kovalam	0.65	0.08	6500	4255.25	527.45
Kanathur	3.09	0.07	5000	15450.00	343.93
Panaiyur	0.56	0.05	6000	3370.45	323.81
Neelankarai	1.10	0.06	9000	9883.85	538.20
Kottivakkam	1.08	0.04	8000	8620.00	335.07
Tirumudivakkam	0.85	0.04	11000	9387.98	386.96
Patinapakkam	1.20	0.06	15000	17973.75	938.13
EnnoreChinnakuppam	0.78	0.06	3500	2734.29	222.60
Koraikuppam	0.45	0.04	11000	4993.21	422.48
Pulicat lighthouse	0.44	0.01	12000	5226.43	147.73

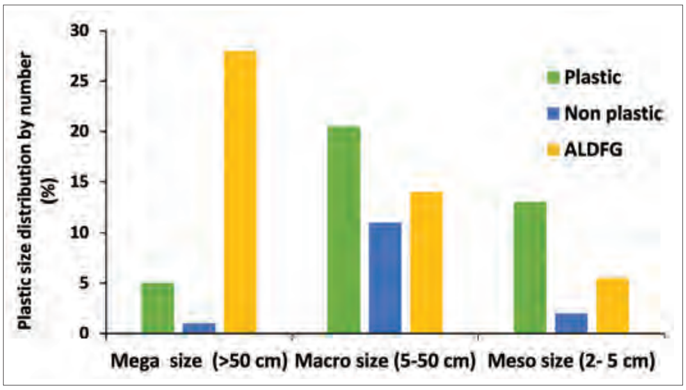


Fig.7.6: Distribution of different sizes and types of the sampled litter

activities, with gear loss common in Tamil Nadu's coastal regions. Meanwhile, mesoplastics, often resulting from the breakdown of larger items, contribute to microplastic pollution, which is less visible but still harmful. To effectively manage marine litter and mitigate marine litter pollution, strategies should focus on both the recovery of large fishing gear and the collection of smaller debris.

7.2.3. Diversity of beach litter

The composition of beach litter along Tamil Nadu's coastline, comprising plastic waste, ALDFG, and non-plastic debris, clearly demonstrates the combined influence of anthropogenic activities and environmental factors on litter accumulation (Fig. 7.7a and 7.7b). Plastic waste accounted for a significant portion of the litter. The major plastic litter items were food wrappers (18.25% by number, 38% by weight), beverage bottles (9.94% by number, 3% by weight), plastic containers (7.81% by number, 2% by weight), bottle caps (25.1% by number, 42% by weight), plastic fragments (6.5% by number, 5% by weight), cigarette butts (3.2% by number, 1.5% by weight), plastic bags (12.13% by number, 1.65% by weight), plastic cups (11.82% by number, 3% by weight), straws (1.14% by number, 0.25% by weight), napkins/masks (1% by number, 2.4% by weight), and syringes (3.11% by number, 1.2% by weight). The dominance of single-use plastics highlights both high consumption rates and inefficiencies in waste management systems, particularly in coastal communities (Lau et al., 2020).

Fishing-related ALDFG, primarily composed of plastic-based gear, was another major contributor. Ropes (65.85%), floats (21.45%), and nets (9.84%) were the most prevalent items, with ropes and nets accounting for the highest weight proportion (47.74%). This reinforces the findings of previous studies (Farias et al., 2018; Krishnakumar et al., 2018; MARESSOL, 2022) that have identified fishing gear, particularly nets and ropes, as major sources of marine debris in coastal regions. Accidental loss and improper disposal of fishing gear contribute significantly to ALDFG, especially in high fishing-density areas like Ammapattinam and Anumanthaikuppam. These areas exhibit patterns of fishing-related pollution similar to other global hotspots (Lebreton et al., 2018).

Interestingly, while the study highlights fishing-related debris as the dominant source of litter, research by Robbe et al. (2023) identified single-use plastics as the primary pollutant on North African coasts. This contrast underscores the regional variability in marine litter sources, with fishing activities being a more significant contributor in some regions compared to others where consumer waste dominates. Understanding these regional differences is crucial for designing effective waste management and mitigation strategies tailored to specific coastal environments.

Additionally, non-plastic debris also plays a role in coastal pollution, with paper and cardboard accounting for 29.3%, followed by glass beverage bottles (28.6%), clothing and shoes (23.03%), and glass fragments (14.56%). Miscellaneous items such as aluminium cans, metal fragments, glass jars, building materials, and organic debris such as fruits and vegetables contributed less than 5% (Fig. 7.8). The presence of non-plastic debris, such as paper, glass bottles and clothing, indicates the diverse nature of coastal pollution. Paper and cardboard, accounting for 29.3% of the litter, can often be linked to domestic waste that is improperly discarded in coastal areas or transported via storm water runoff. This suggests that fishing-related activities are not the sole contrib-

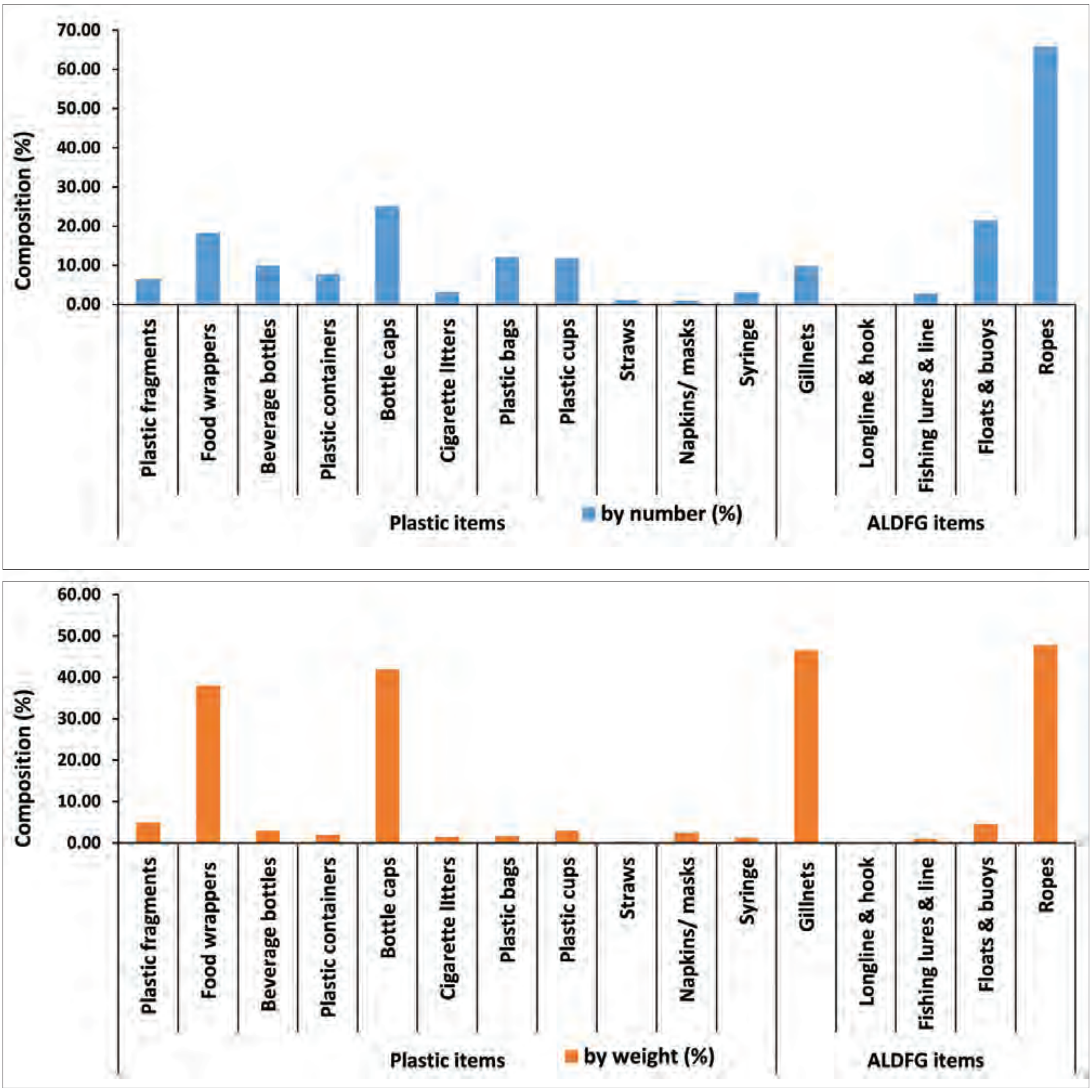


Fig. 7.7a & b: Composition of beach Litter Items by Number (a) and Weight (b) for plastic litter and ALDFG fisheries-related litter

utors to coastal litter. General urbanization and inadequate waste management practices also play a significant role.

The heat map in Fig. 7.9 presents a visual description of the abundance of marine debris at different sites, with dark pink representing a higher concentration of debris. The list of debris is found on the left side, while unique sample sites are found at the top. This map shows that the most common type of debris is rope, which is found at the sites ofNeerody, Muttom, Kuthenkul-ly, Uvari, Periyathalai, Manapad, Rameswaram, Mandapam North, Alagankulam, Devipattinam,

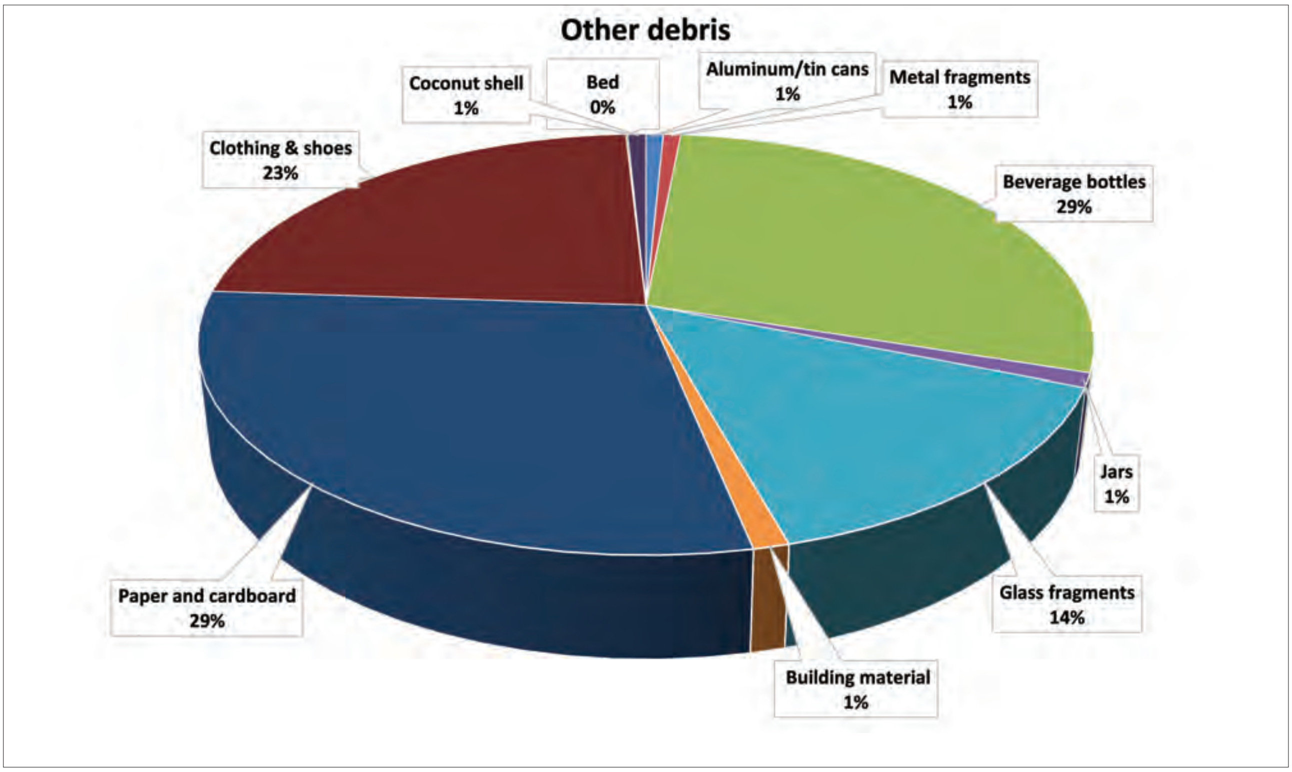


Fig.7.8: Share of other debris in the beach litter

Mullimunai, Dhamothirapattinam, Ammapattinam, Manamelkudi, Sethubavachatram, Kodiyakarai, Vellapallam, Amirthanagar, Perumalpettai, Khoduvai, Kayalpattu, Devanampattinam, Bommiyarpaalayam, Anumanthaikuppam, Panaiyurkuppam, KadalurPeriyakuppam, Mahabalipuram, Vadanemmeli, Kovalam, Panaiyur, Neelankarai, Kottivakkam, Tirumudivakkam, Patinapakkam and EnnoreChinnakuppam. Other usual debris of plastic cups, plastic bags, plastic containers and food wrappers dominate at the sites of Neerody, Kuthenkully, Uvari, Devipattinam, Vellapallam, Amirthanagar, Khoduvai, Samiyarpettai, Kayalpattu, Devanampattinam, KadalurPeriyakuppam, Mahabalipuram, Kovalam, Panaiyur, and Tirumudivakkam. Shattered metal fragment dominates at most sites namely Neerody, Kuthenkully, Uvari, Alagankulam, Devipattinam, Sethubavachatram, Amirthanagar, Khoduvai, Kayalpattu, Devanampattinam, KadalurPeriyakuppam, Panaiyur, and Neelankarai. Moderate amounts of beverage bottles, clothing and shoes, cigarette litter, and plastic fragments were found scattered across several sites. In contrast, the sites of Pallam, K Kovalam, Arockiyapuram, Kulasekarapatnam, Thangachimadam North, Thondi, Muthukuda, Arucottuthurai, Pushpavanam, Kameswaram, Nagapattinam and Pulicat Lighthouse exhibited relatively low debris levels, except for moderate amounts of fishing lures and lines in some locations. Overall, the map highlights rope and plastic-based items as the most dominant type of marine debris, while other items, such as metal fragments, building materials, and traps, were less dominant and varied in distribution across coastal sites. The heat map also shows the interplay of human activities and environmental forces in determining the patterns of litter along the coast, thereby indicating the necessity of region-specific waste management policies.

7.3. Chemical composition of beach litter

The chemical composition of plastic litter collected from Tamil Nadu beaches was analyzed using Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (ATR-FTIR). This analysis

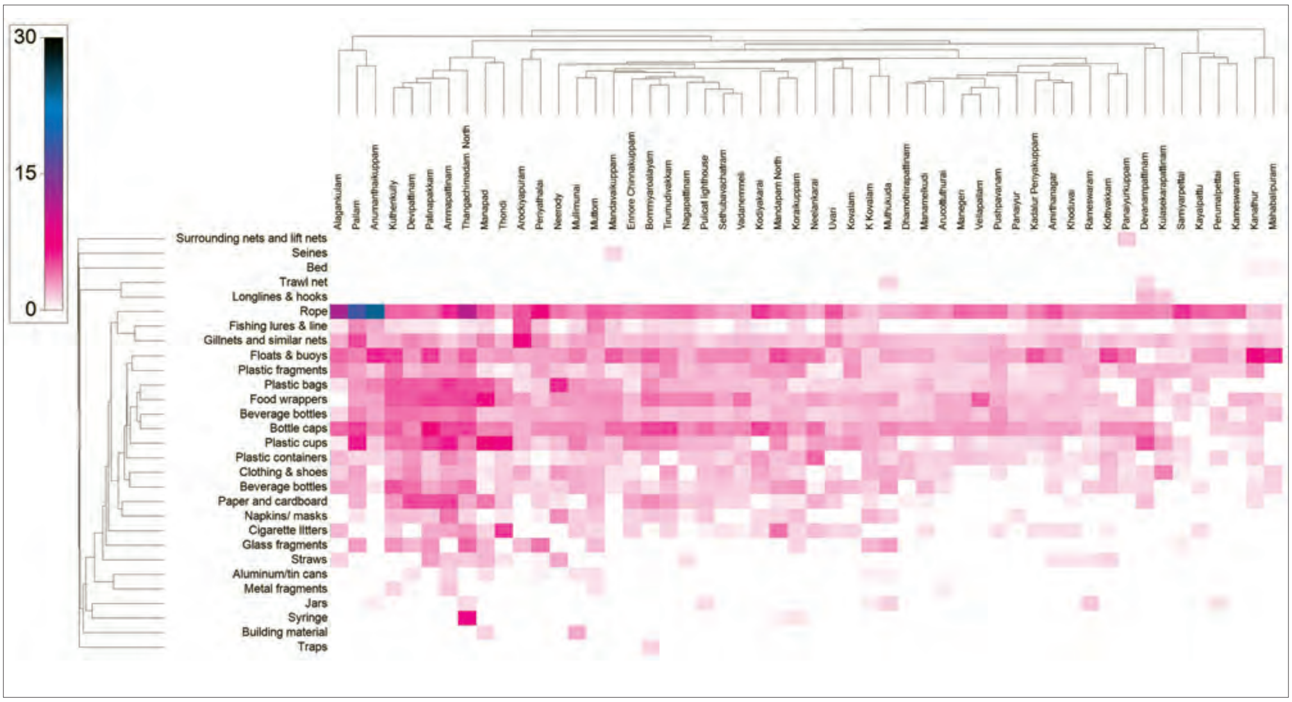


Fig. 7.9: Heat Map showing the spatial distribution of beach litter items across different sites (Sites 1-52 as shown in Fig.1)

provided significant insights into the types of polymers contributing to coastal pollution. Out of 5,341 plastic litter items, 72% (n=3,850) were analyzed for polymer identification, revealing a diverse range of 20 distinct polymers. The number of items collected from each site, along with their percentage of the overall sample, is detailed in Table 7.4. The identified polymer types, along with their respective counts and percentages, are provided in Table 7.5.

Polyethylene (PE) was the most prevalent polymer, accounting for 27.43% (n=1,056) of the total, followed by polypropylene (PP) for 20.39% (n=785), polyethylene terephthalate (PET) for 9.48% (n=365), and polyamide (PA6/PA66) for 9.22% (n=355). Other notable polymers included polystyrene (PS) and expanded polystyrene (EPS) at 6.49% (n=250), polyvinyl chloride (PVC) at 4.03% (n=155), polyether urethane (PEU) at 3.77% (n=145), and cellophane (CP) at 3.30% (n=127). Together, these polymers accounted for 84.10% of the total samples analyzed, underscoring their prevalence in both household and fishing-related waste.

The remaining 15.89% (n=612) comprised less common polymers, including polyethylene: propylene (PE: PP) at 1.09% (n=42), polyvinylidene fluoride (PVDF) at 1.35% (n=52), polyacrylonitrile (PAN) at 1.71% (n=66), polycarbonate (PC) at 2.21% (n=85), polymethylmethacrylate (PMMA) at 1.95% (n=75), polytetrafluoroethylene (PTFE) at 1.14% (n=44), polyvinyl acetate (PVA) at 1.69% (n=65), cellulose acetate (CA) at 1.43% (n=55), polyvinyl fluoride (PVF) at 0.39% (n=15), ethylene vinyl acetate (EVA) at 1.43% (n=55), alkyd resin (AR) at 0.65% (n=25), and acrylonitrile-butadiene-styrene (ABS) at 0.86% (n=33) (Fig.7.10). The FTIR peaks for each polymer are provided in the supplementary materials (Fig. 7.11).

The distribution of polymers varied significantly across different litter types, reflecting distinct anthropogenic and environmental influences. For instance, food wrappers predominantly contained PP (24%), PE (22.25%), PET (23.92%), and CP (8%), with smaller proportions of PVC and PS. Plastic fragments, excluding ALDFG, were mainly composed of PE (34%), PP (27.15%), and PET (11.85%), followed by PS and PVC.

Table 7.4. Total plastic litter collected from each fishing village for polymer identification

Beach name	Sample count * (Number (n) of plastic items analysed)	Percentage (%)
Neerody	85	2.21
Muttom	95	2.47
Pallam	151	3.92
K Kovalam	45	1.17
Arockiyapuram	87	2.26
Periyathalai	89	2.31
Uvari	54	1.40
Kuthenkully	84	2.18
Kulasekarapattinam	32	0.83
Manapad	80	2.08
Rameswaram	95	2.47
Thangachimadam North	80	2.08
Mandapam North	78	2.03
Alagankulam	70	1.82
Devipattinam	82	2.13
Mullimunai	78	2.03
Thondi	89	2.31
Dhamothirapattinam	30	0.78
Muthukuda	50	1.30
Ammapattinam	99	2.57
Manamelkudi	30	0.78
Sethubavachatram	78	2.03
Kodiyakarai	82	2.13
Arucottuthurai	25	0.65
Pushpavanam	55	1.43
Vellapallam	48	1.25
Kameswaram	25	0.65
Nagapattinam	67	1.74
Amirthanagar	50	1.30
Perumalpettai	25	0.65
Manegeri	40	1.04
Khoduvai	40	1.04
Samiyarpettai	35	0.91
Kayalpattu	30	0.78
Devanampattinam	57	1.48
Mandavaikuppam	79	2.05
Bommiyaroalayam	119	3.09
Anumanthaikuppam	534	13.88
Panaiyurkuppam	50	1.30
KadalurPeriyakuppam	50	1.30
Mahabalipuram	33	0.86
Vadanemmeli	65	1.69
Kovalam	45	1.17
Kanathur	78	2.03
Panaiyur	20	0.52
Neelankarai	75	1.95
Kottivakkam	67	1.74
Tirumudivakkam	100	2.57
Patinapakkam	245	6.36
EnnoreChinnakuppam	60	1.56
Koraikuppam	75	1.95
Pulicat lighthouse	69	1.79

Note: *n = Each item represents a physically distinct piece of plastic collected from beach transects and analyzed using ATR-FTIR.

Beverage bottles were primarily made of PET (44.15%), with PE (28%) and PP (16.85%). Plastic containers were mostly PE (44.58%) and PET (18.51%). Bottle caps consisted mainly of PE (43.56%) and PP (31.91%), while cigarette litter was composed of PE (40.55%) and PP (19%). Plastic bags were dominated by PP (48.62%) and PE (40.38%). Plastic cups were primarily made of PE (59.03%) and PP (23.85%), while straws were predominantly PP (77.58%). Napkins and masks showed a composition of PE (53.22%) and PP (36.28%). Syringes were mainly composed of PE (74.23%) and PP (25.77%). Fishing nets contained a majority of PA (44.15%), followed by PE (36.18%) and PP (10.04%). Longlines were primarily PA (45.31%) and PE (38.85%), while floats and buoys mainly had PS (32.17%), PE (24.15%), and PVC (12.77%). Ropes consisted of PE (35%), PP (33.3%), and PA (19.75%). Fishing lures were mostly made of PE (58.10%) and PP (10.21%), with smaller amounts of PS, PMMA, and other polymers.

7.3.1. Principal component analysis and Hierarchical clustering dendrogram

The PCoA (Fig.7.12) and PCA analyses (Fig.7.13) collectively highlighted beach litter's spatial variation and composition across the 52 coastal

Table 7.5. Number and percentage of plastic items identified by polymer type using ATR-FTIR

Polymers	Plastic items per polymer type (n)	Percentage (%)
PE	1056	27.43
PP	785	20.39
PE: PP	42	1.09
PA	355	9.22
PVDF	52	1.35
PVC	155	4.03
PS	250	6.49
PEU	145	3.77
CP	127	3.30
PAN	66	1.71
PET	365	9.48
PC	85	2.21
PMMA	75	1.95
PTFE	44	1.14
PVA	65	1.69
CA	55	1.43
PVF	15	0.39
EVA	55	1.43
AR	25	0.65
ABS	33	0.86

sites in Tamil Nadu. The PCoA plot explained 34.8% of the total variation along PC1 and 11.5% along PC2. The greatest proportion of variation was accounted for by PC1, dominated by fishing-type debris, which included seine, trawl net, and long lines. High values of PC1 were observed in sites 9 (Tuticorin district) 20 (Ammapattinam), 37 (Anumanthaikuppam) and 12 (Ramanathapuram district), with dominant fishing activities. PC2, associated with urban and recreational waste, included plastics, ropes, cigarette butts, and glass shards, with high values at sites 44 and 47 (Chennai district) and 30 (Mayiladuthurai district). High litter zones were well represented by Villupuram, Ramanathapuram, Pudukottai, Tuticorin, and Chennai districts through intensive fishing activities, urbanization, and tourism. Thanjavur and Kanniyakumari districts were found to be low litter zones, depicting better waste management and low human influence. Notable outliers, including site 33 (Cuddalore district) and 38 (Villupuram district), display unique litter profiles linked to localized activities. The PCA plot again confirms these trends, with

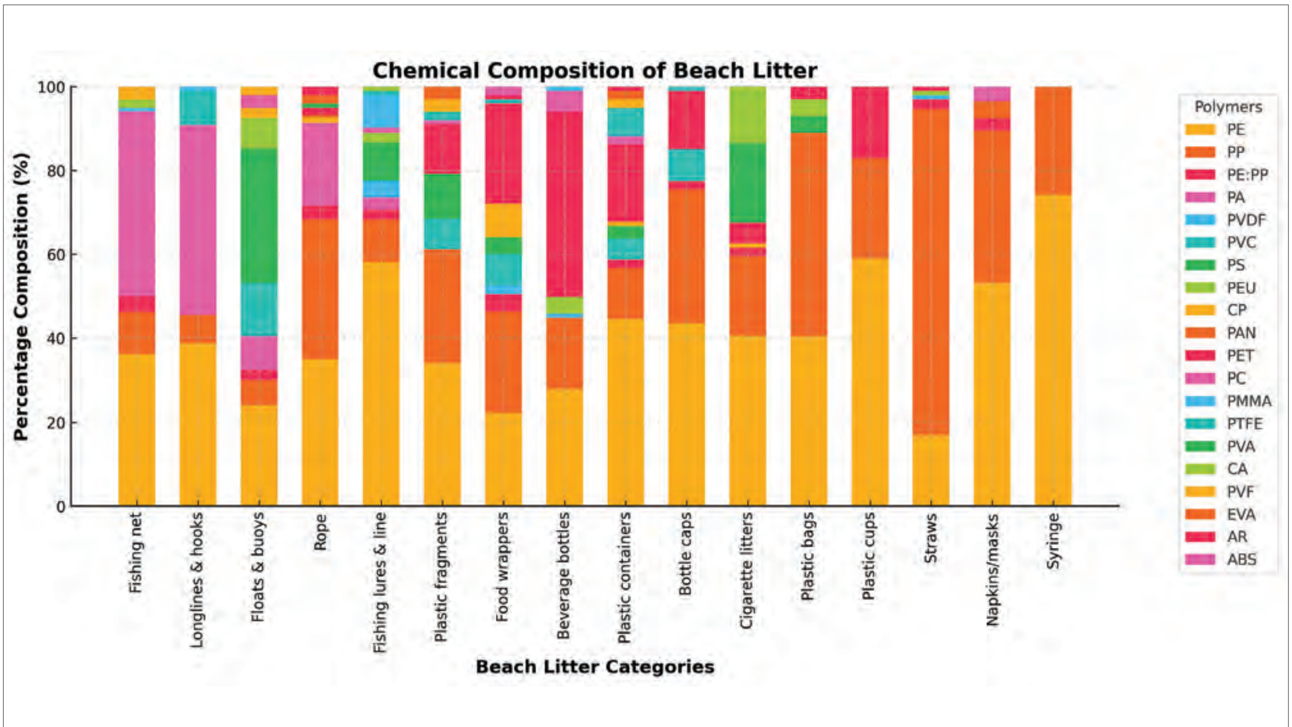
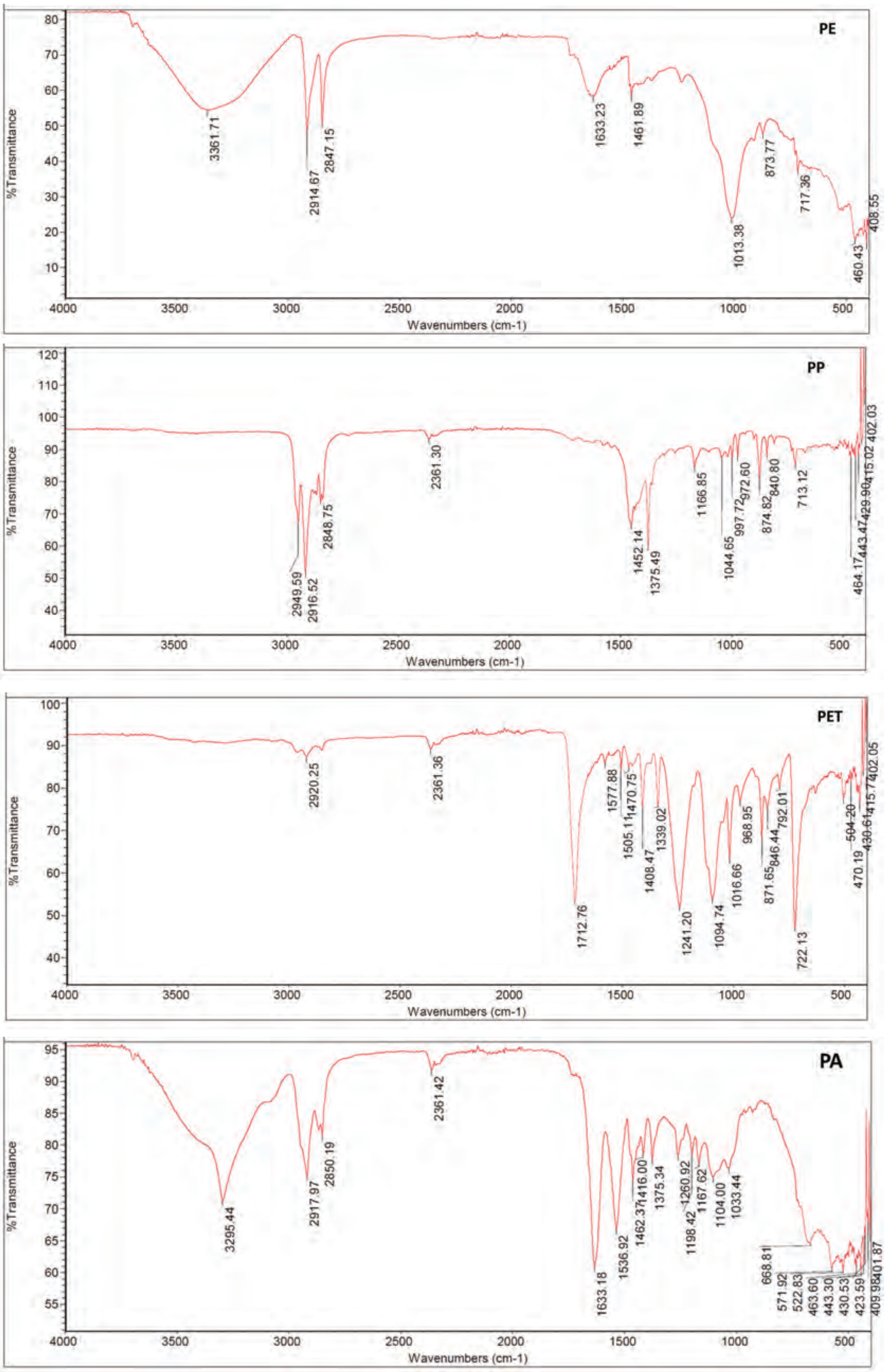
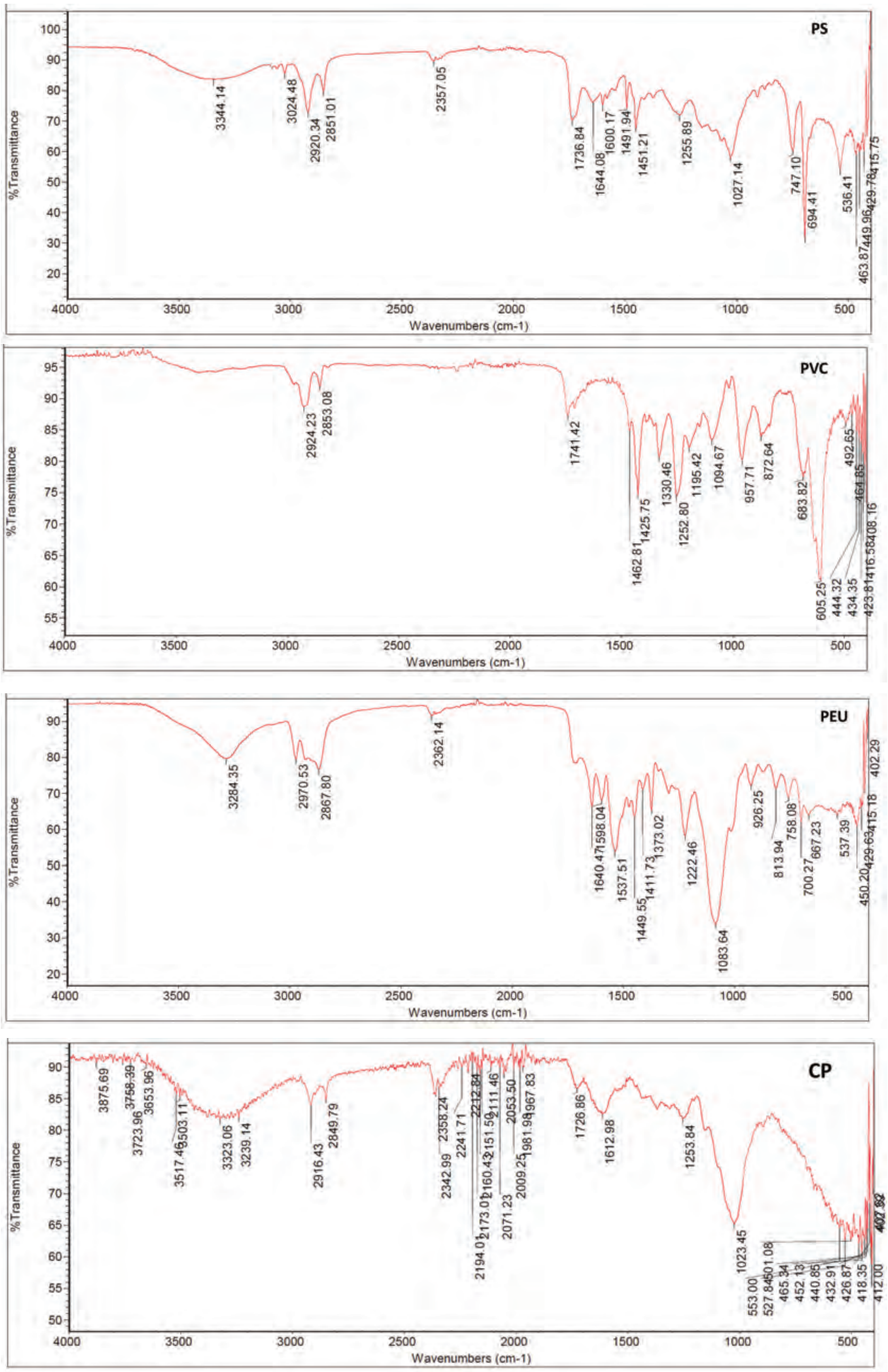
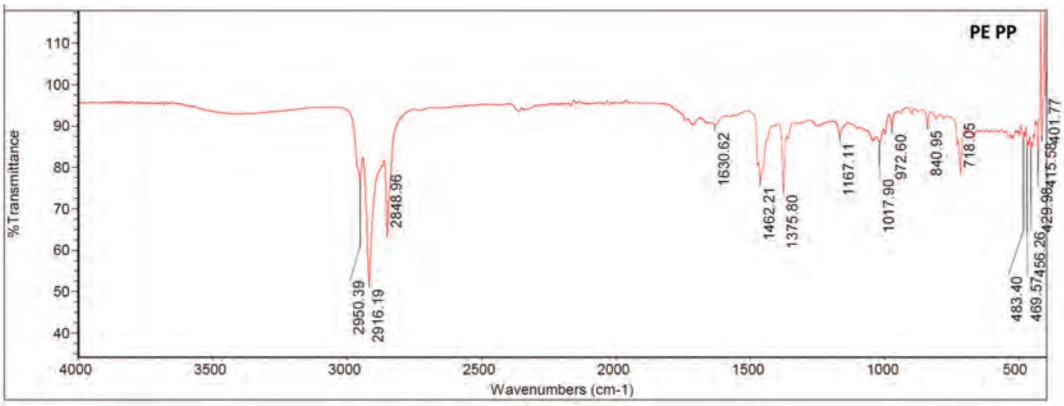
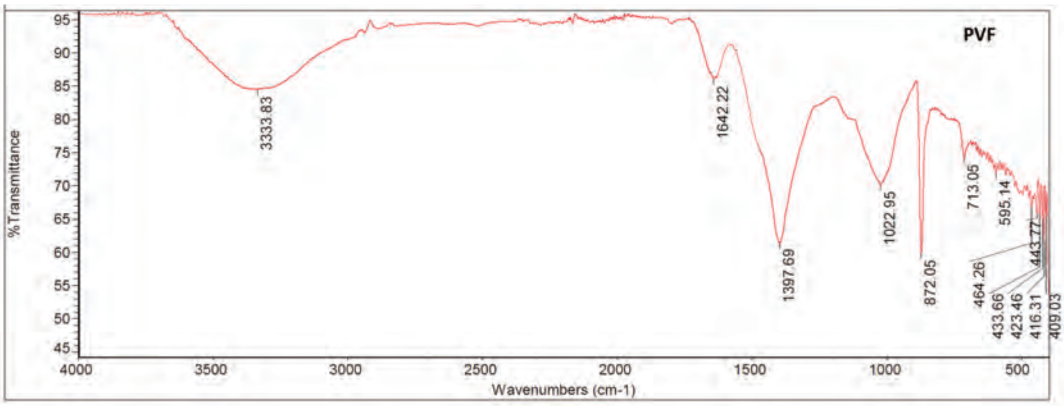


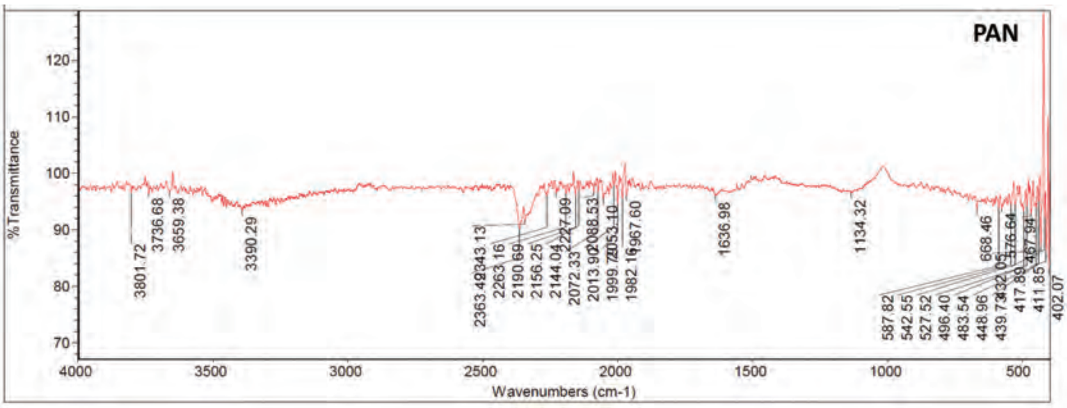
Fig.7.10: Polymer composition of different types of beach marine debris, calculated by number of items

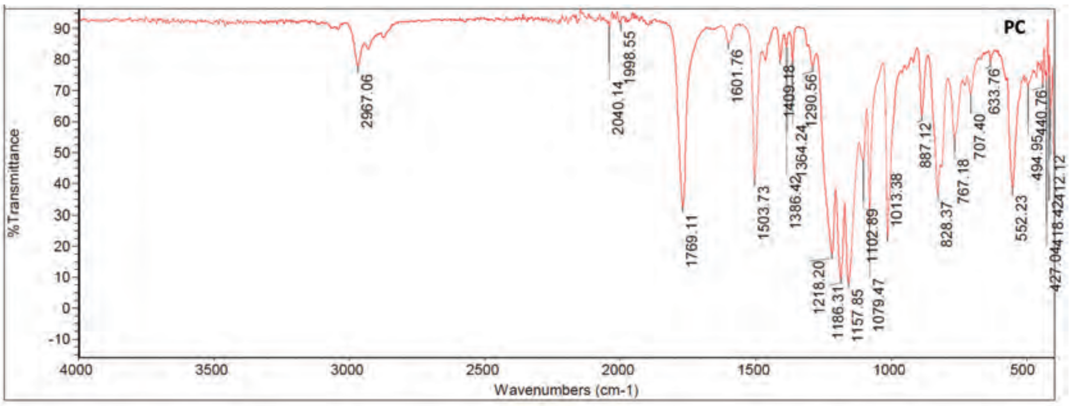

PE
%Transmittance
Wavenumbers (cm-1)
3361.71
2914.67
2847.15
1633.23
1461.89
1013.38
873.77
717.36
460.43
408.55
PP
%Transmittance
Wavenumbers (cm-1)
2949.59
2916.52
2848.75
2361.30
1452.14
1375.49
1166.85
1044.65
997.72
972.60
874.82
840.80
713.12
464.17
443.47
429.90
415.02
402.03
PET
%Transmittance
Wavenumbers (cm-1)
2920.25
2361.36
1712.76
1577.88
1505.11
1470.75
1408.47
1339.02
1241.20
1094.74
1016.66
968.95
871.65
846.44
792.01
722.13
504.20
470.19
430.61
415.74
402.05
PA
%Transmittance
Wavenumbers (cm-1)
3295.44
2917.97
2850.19
2361.42
1633.18
1536.92
1462.37
1416.00
1375.34
1260.92
1198.42
1167.62
1104.00
1033.44
668.81
571.92
522.83
463.60
443.30
430.53
423.59
409.98
401.87

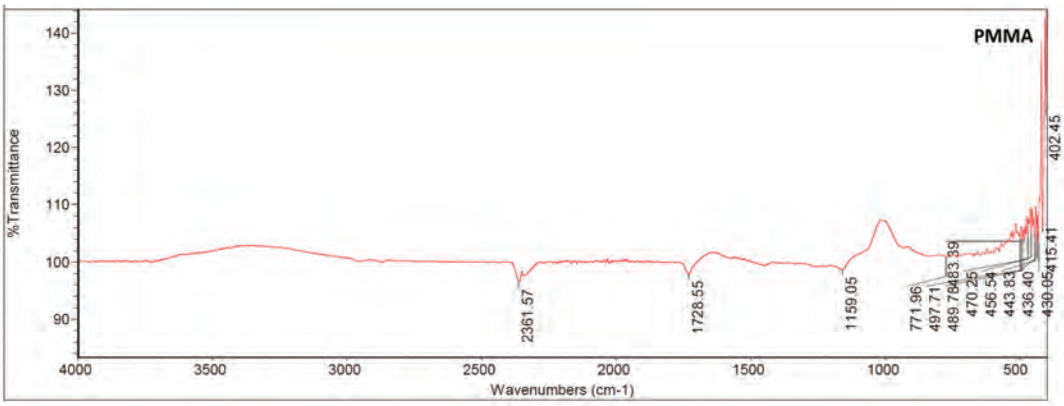

PS
%Transmittance
Wavenumbers (cm-1)
3344.14
3024.48
2920.34
2851.01
2357.05
1736.84
1644.08
1600.17
1491.94
1451.21
1255.89
1027.14
747.10
694.41
536.41
463.87
449.96
429.78
415.75
PVC
%Transmittance
Wavenumbers (cm-1)
2924.23
2853.08
1741.42
1462.81
1425.75
1330.46
1252.80
1195.42
1094.67
957.71
872.64
683.82
605.25
492.65
464.85
444.32
434.35
423.81
416.58
408.16
PEU
%Transmittance
Wavenumbers (cm-1)
3284.35
2970.53
2867.80
2362.14
1640.47
1598.04
1537.51
1449.55
1411.73
1373.02
1222.46
1083.64
926.25
813.94
758.08
700.27
667.23
537.39
450.20
429.63
415.18
402.29
CP
%Transmittance
Wavenumbers (cm-1)
3875.69
3758.39
3723.96
3653.96
3517.46
3503.11
3323.06
3239.14
2916.43
2849.79
2358.24
2342.99
2241.71
2212.84
2194.01
2173.01
2160.43
2151.50
2111.46
2071.23
2053.50
2009.25
1981.98
1967.83
1726.86
1612.98
1253.84
1023.45
553.00
527.84
501.08
465.34
452.13
440.86
432.91
426.87
418.35
412.00


PE PP
%Transmittance
Wavenumbers (cm-1)
2950.39
2916.19
2848.96
1630.62
1462.21
1375.80
1167.11
1017.90
972.60
840.95
718.05
483.40
469.57
456.26
429.98
415.58
401.77


PVF
%Transmittance
Wavenumbers (cm-1)
3333.83
1642.22
1397.69
1022.95
872.05
713.05
595.14
464.26
443.77
433.66
423.46
416.31
409.03


PAN
%Transmittance
Wavenumbers (cm-1)
3801.72
3736.68
3659.38
3390.29
1636.98
1134.32
668.46
402.07


PC
%Transmittance
Wavenumbers (cm-1)
2967.06
2040.14
1998.55
1769.11
1601.76
1503.73
1409.18
1386.42
1364.24
1290.56
1218.20
1186.31
1157.85
1102.89
1079.47
1013.38
887.12
828.37
767.18
707.40
633.76
552.23
494.95
440.76
412.12


PMMA
%Transmittance
Wavenumbers (cm-1)
2361.57
1728.55
1159.05
771.96
497.71
489.78
483.39
470.25
456.54
443.83
436.40
430.05
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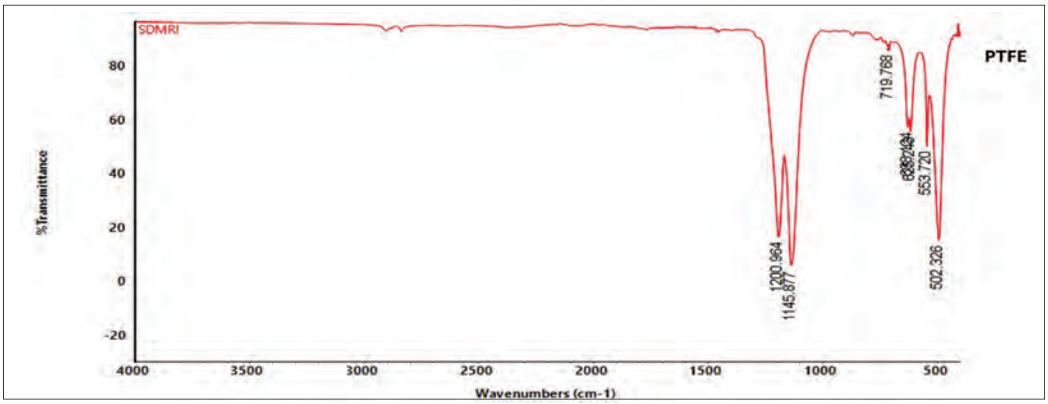
402.45


SDMRI
PTFE
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Wavenumbers (cm-1)
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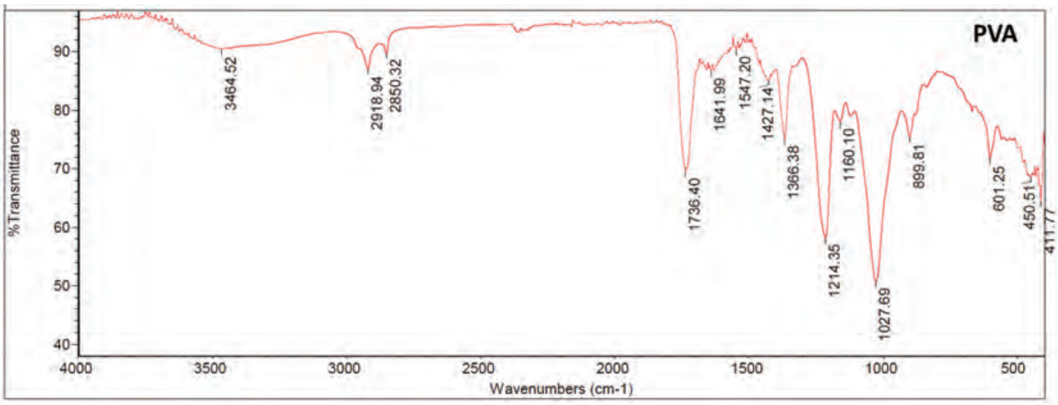
553.720
1200.964
1145.877
502.326


PVA
%Transmittance
Wavenumbers (cm-1)
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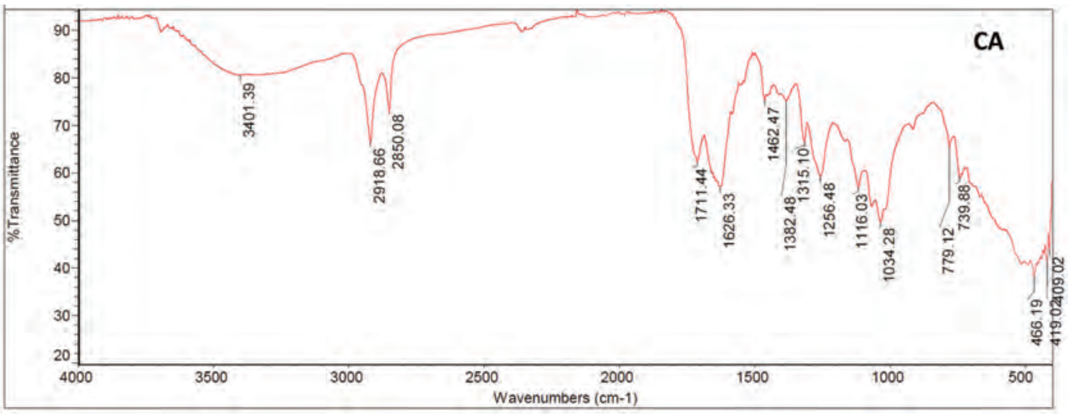
2918.94
2850.32
1736.40
1641.99
1547.20
1427.14
1366.38
1214.35
1160.10
1027.69
899.81
601.25
450.51
411.77


CA
%Transmittance
Wavenumbers (cm-1)
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2850.08
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1315.10
1256.48
1116.03
1034.28
779.12
739.88
466.19
419.02
409.02

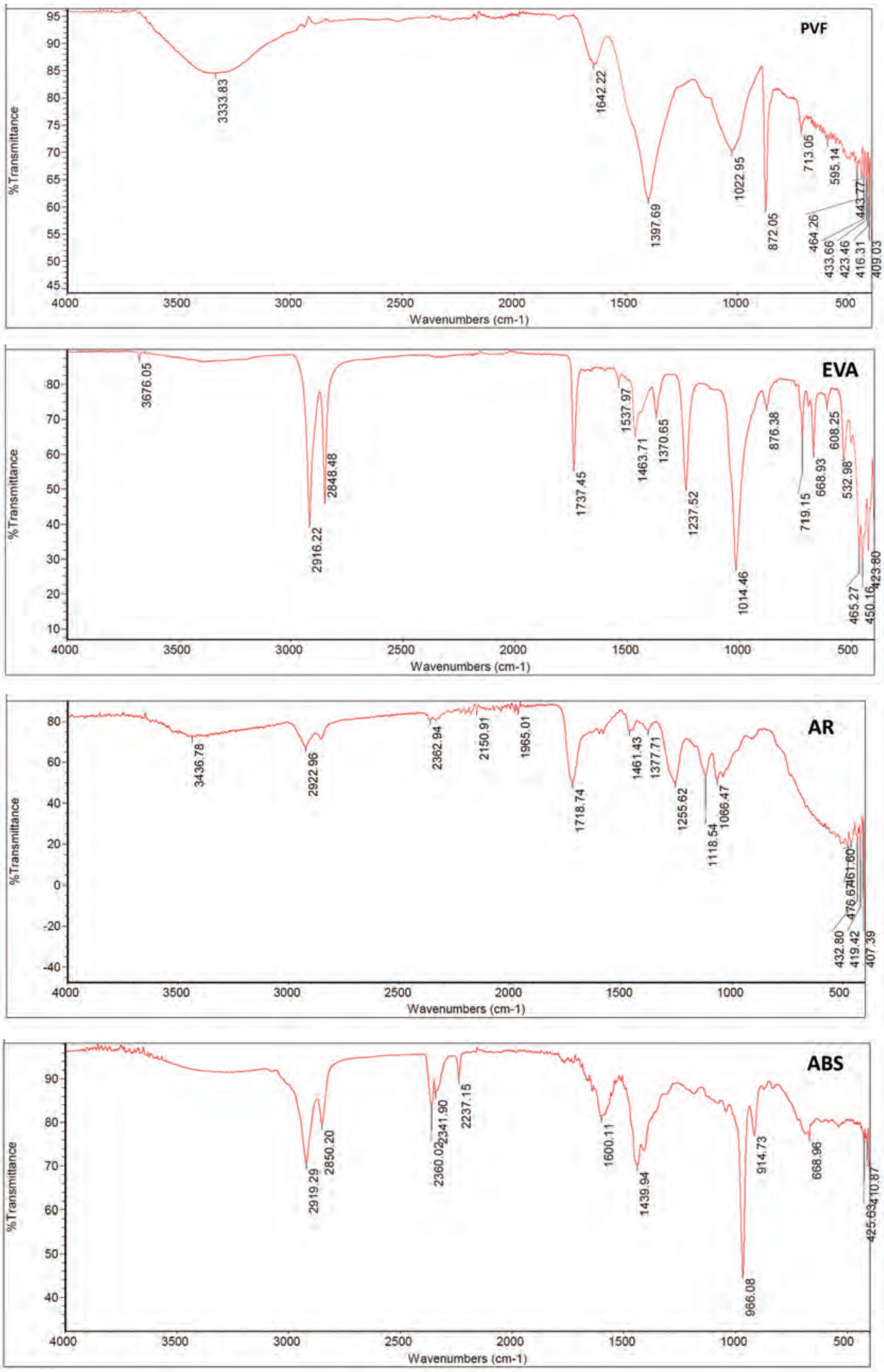


Fig. 7.11: FTIR spectra for the identified polymers

marked regional differences in litter composition. Districts like Pudukottai, Villupuram, Tuticorin, Ramanathapuram, had more fishing gear as contributors, and Nagapattinam and Mayiladuthurai showed more surrounding nets. Urban cities like Chennai and Chengalpattu also showed a more diverse mix, including cigarette butts and beverage bottles. Overall, the analyses showed that litter is not uniformly spread along the Tamil Nadu coast, but occurs in patches because of fishing, urban runoffs, and tourism. These insights underscore the urgent need for region-specific waste management strategies, focusing on fishing debris reduction and robust plastic waste initiatives, to mitigate litter pollution effectively.

The dendrogram shows the clustering of study sites of the Tamil Nadu coast based on the composition in which beach litter is found. It has been created using the group average linkage method where distance among points within the clusters is averaged to calculate the similarity between sites. The x-axis represents the degree of similarity (Fig. 7.14). Greater values mean an increased similarity in the composition of plastics, while the y-axis shows the sites with their district identifier. Sites are broadly put into three clusters. Group 1 includes most of the sites (Mandavaikuppam, Thangachimadam North, Ammapattinam, Patinapakkam, Periyathalai, Devipattinam, Kulasekarapatnam, Uvari, Mullimunai, Samiyarpettai, Mahabalipuram, KadalurPeriyakuppam, Panaiyurkuppam, Khoduvai, Panaiyur, Pushpavanam, Arucottuthurai, Dhamothirapattinam, Manamelkudi, Muthukuda, Mandapam North, Neelankarai, Arockiyapuram and Kodiyakarai), which have similar plastic composition, probably indicating a shared source by either fish-

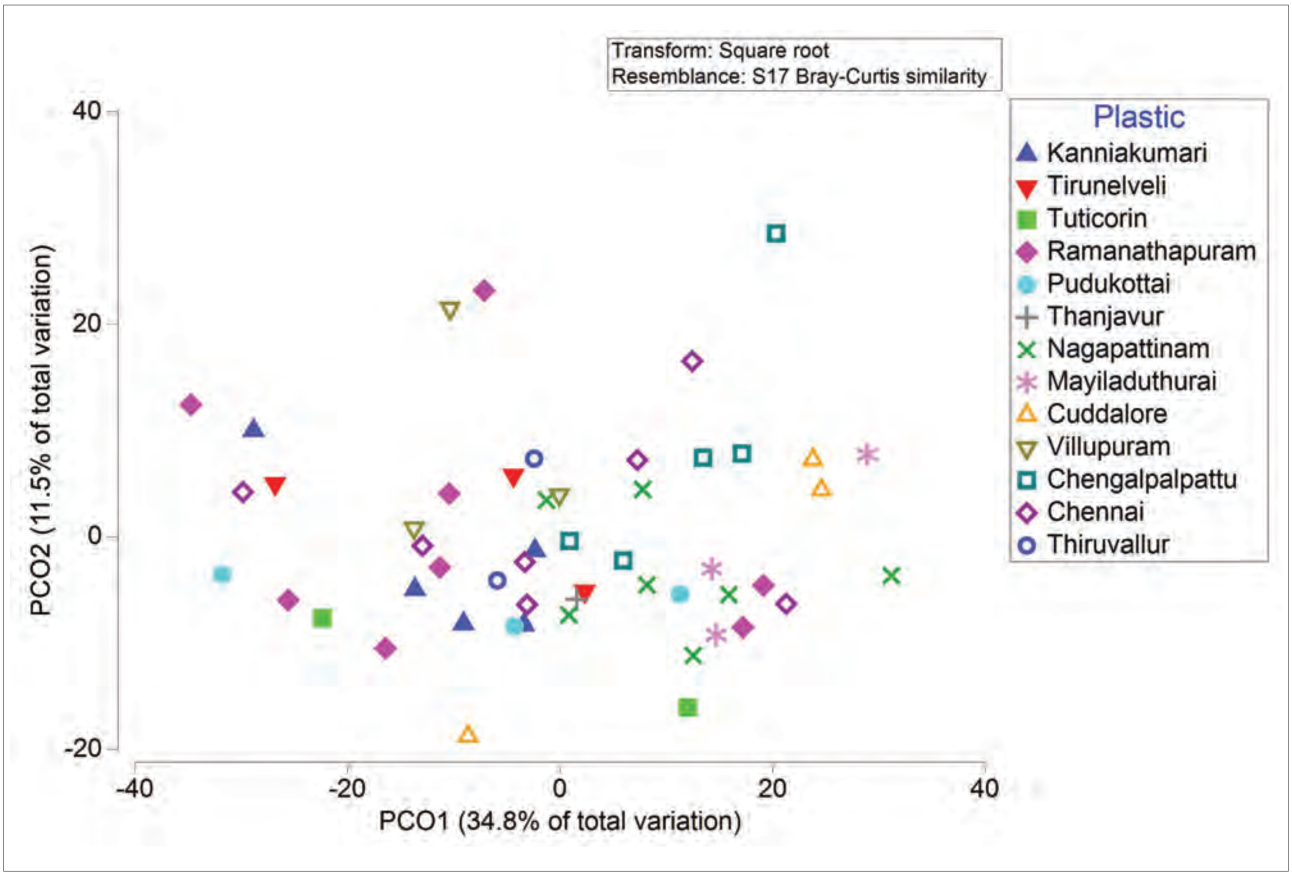


Fig.7.12: Principal Coordinates Analysis (PCoA) illustrating the spatial variation of beach litter along Tamil Nadu coast (Sites 1-52 as shown in Fig.1)

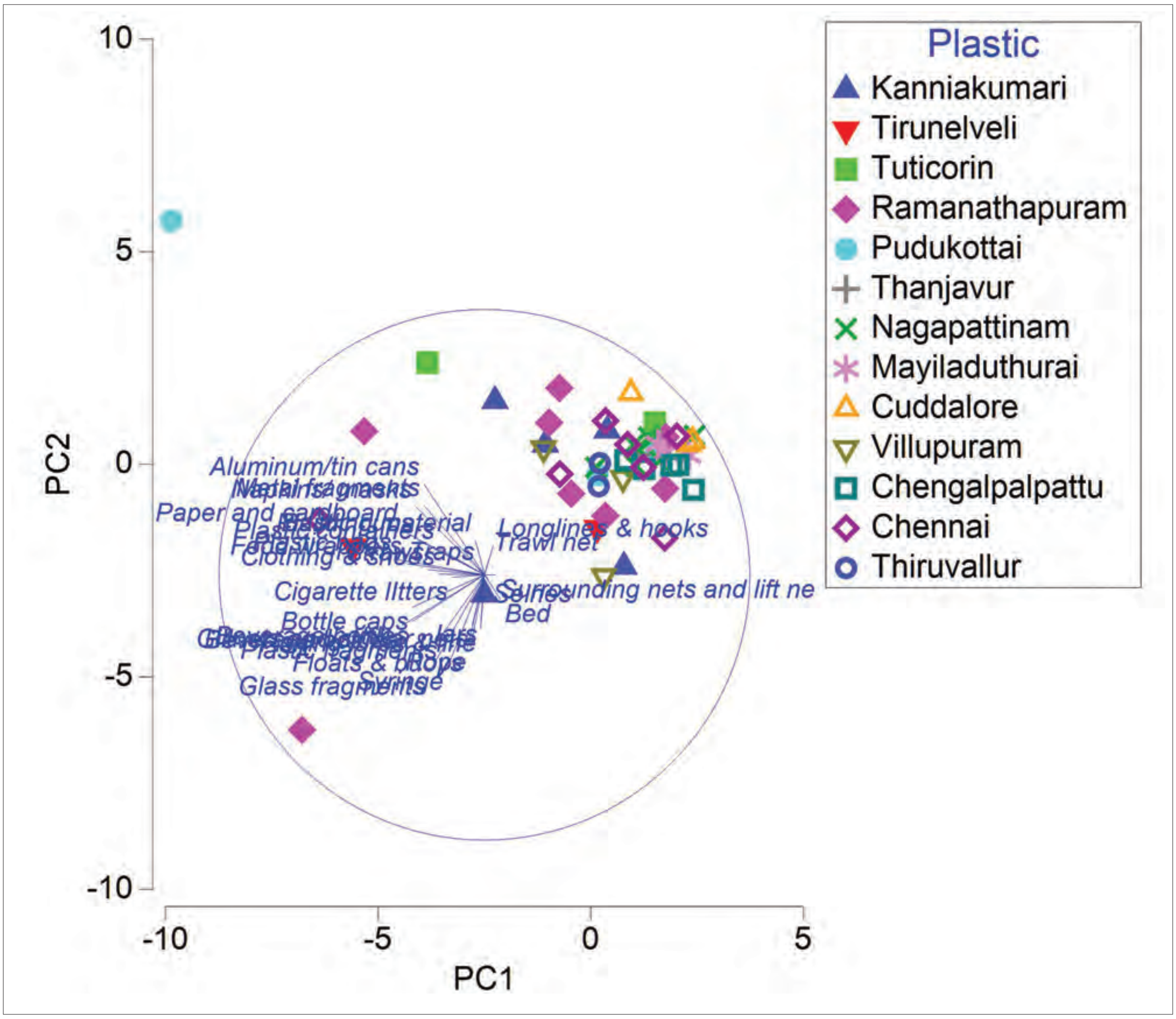


Fig. 7.13: Principal Component Analysis (PCA) of beach litter collected from 13 districts along the Tamil Nadu coast (Sites 1-52 as shown in Fig.1)

ing activities or urban wastes. Group 2 includes Kovalam, Koraikuppam, K Kovalam, Bommiyarpaalayam, Nagapattinam, Pulicat Lighthouse, Sethubavachatram, and Vadanemmeli. Sites 43, 51, 4, 36, 28, 52, 22, and 42, are somewhat similar to Group 1 but different in their characteristics, which could be related to local waste disposal practices. Group 3, with the outliers 50, 37, 48, 9, and 35, has the least similarity, which may be related to site-specific sources of plastic, unique environmental conditions, or geographical isolation. These clusters indicate that distribution of plastics is highly influenced by geographic proximity, human activities like fishing and urbanization, and environmental factors like ocean currents and wind patterns. The diversity of plastic composition within these clusters brings out the fact that region-specific interventions are a must to take care of various sources and compositions of plastic waste. This study highlights the heterogeneity of plastic pollution along the Tamil Nadu coast and underlines the need for management strategies as per the situation.

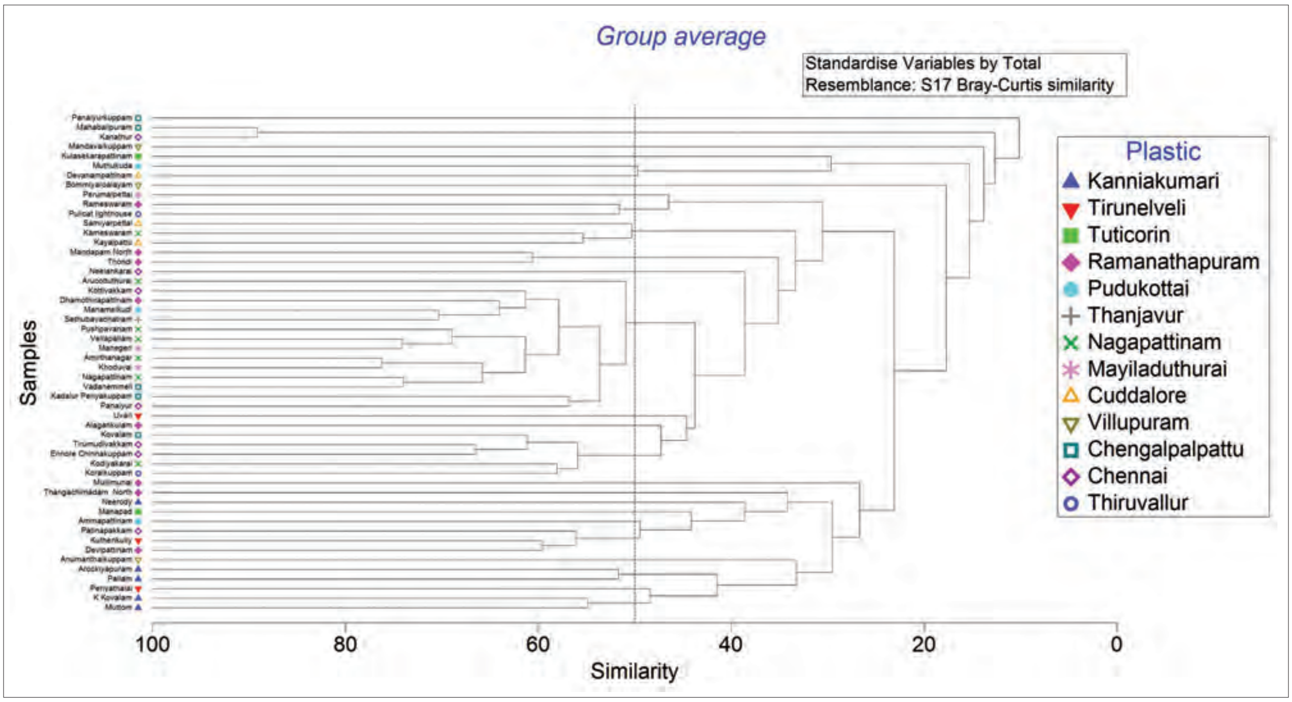


Fig. 7.14: Dendrogram analysis illustrating the beach litter distribution patterns across Tamil Nadu coastal sites (Sites 1-52 as shown in Fig.1)

7.4. Sources of beach litter

Identifying the sources of beach litter is critical for developing effective mitigation strategies. In Tamil Nadu, beach litter originates from both marine-based and land-based sources, contributing significantly to plastic and non-plastic pollution on the coastline (Fig.7.15).

Among marine-based sources, abandoned, lost, discarded, and end-of-life fishing gear emerged as a dominant contributor. Fishing nets, ropes, lines, and traps accounted for a significant portion of marine debris, with particularly high concentrations in Villupuram (79%), Pudukottai (65%), Kanniyakumari (61%), and Tuticorin (60%). Fishing ropes alone constituted 65.85% of collected waste, followed by floats and buoys (21.45%). These items, commonly known as ghost gear, drift with ocean currents, accumulate on beaches and degrade into microplastics over time.

In addition to ALDFG, net mending and preparation activities contribute significantly to marine plastic pollution. During routine gear maintenance, small net fragments (0.5-2.5 cm) are discarded onshore, adding to persistent mesoplastic pollution. This source is often overlooked in clean-up initiatives, underscoring the need for targeted management strategies beyond macro- and microplastic pollution.

Land-based sources also play a crucial role in beach litter accumulation. Plastic debris from coastal communities, tourism, and unregulated landfills often enters the marine environment through stormwater runoff, rivers, and direct dumping. Among the most common plastic waste items found on Tamil Nadu's beaches were bottle caps (25%), food wrappers (19%), and plastic bags (12%). Ten of the 52 surveyed sites, including Periyathalai, Vellapallam, Thondi, and Koraikuppam, were identified as major waste dumping zones, with household waste (59.27%), fishery bycatch waste (23%), and ALDFG (17.72%) being the most prevalent waste types. These findings highlight the complex and interlinked nature of beach litter sources, requiring an inte-

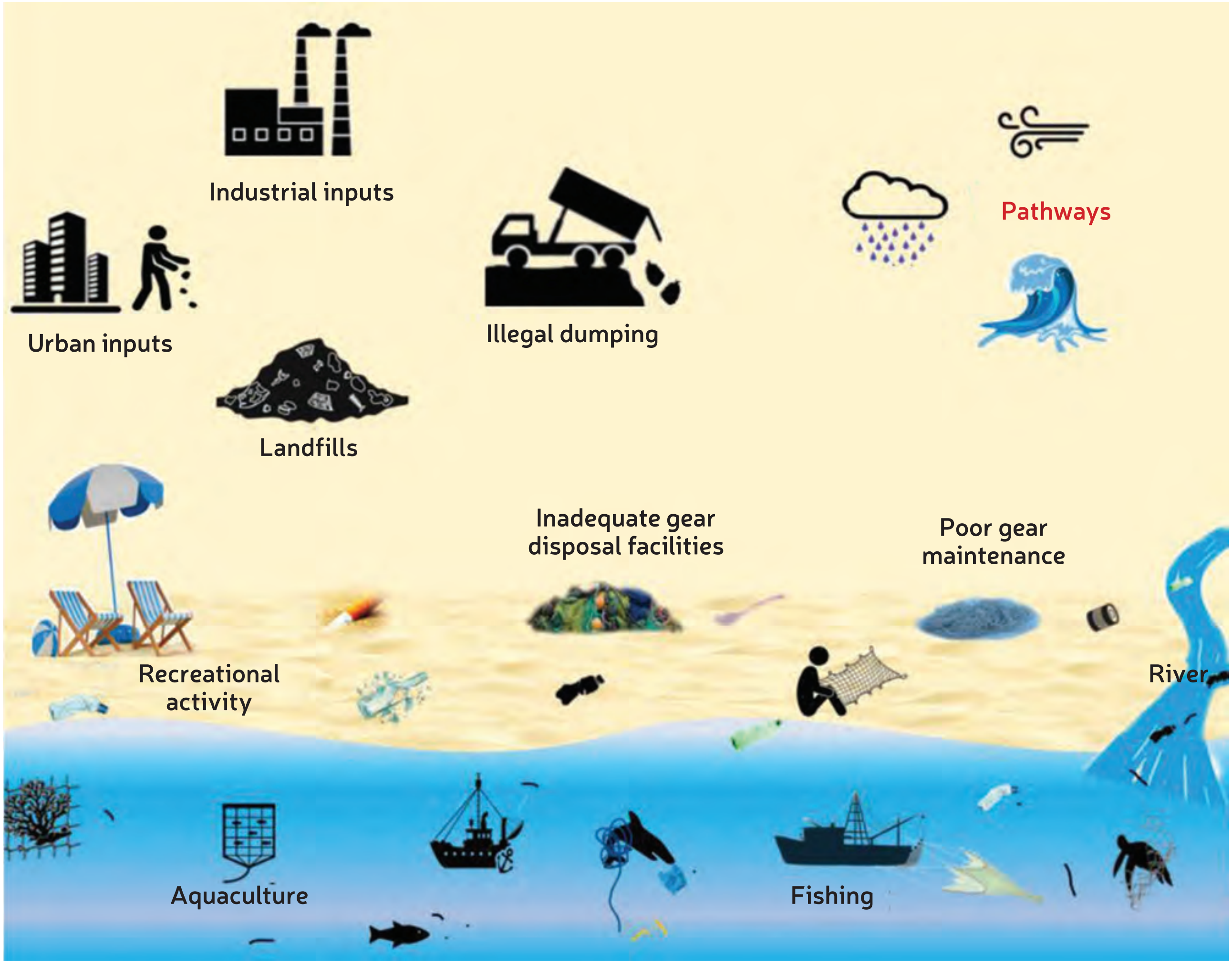


Fig. 7.15: Sources and pathways of marine litter pollution

grated approach to address both marine-based and land-based pollution.

7.4.1. Pathways of marine litter deposition on beaches

Marine litter arrives onshore through multiple pathways, influenced by both natural forces and human activities.

- **Sea-based inputs:** ALDFG and fishing-related debris enter the ocean due to accidental losses, abandonment, or the lack of adequate disposal facilities. These materials are transported by ocean currents and monsoonal winds, leading to their deposition on beaches sometimes far from their original sources. The presence of ALDFG and floating plastics along the Tamil Nadu coastline suggests transboundary movement of marine litter, in addition to the local sources, further exacerbating the pollution condition (Lincoln et al., 2022).

- **Land-based inputs:** Rivers, stormwater runoff, and direct dumping carry the inland waste to coastal areas. Improper waste disposal by coastal communities and unregulated landfills significantly contribute to beach litter. Lightweight plastics such as food wrappers, bottles, and bags are particularly susceptible to wind and water-borne transport. Seasonal weather patterns, especially monsoon-driven coastal flooding further increase the deposition of inland waste onto beaches (Chitaka et al., 2023).

- **Residential and Industrial Inputs:** Waste from households and industries, including untreated sewage and improperly disposed plastics, enters the ocean through storm water outlets and sewage pipelines.

- **Landfills:** Inadequate and improper waste management leads to debris being washed into water bodies, ultimately reaching coastal and marine environments.

- **Recreational activities:** Tourists, beachgoers, and local vendors frequently leave behind single-use plastics, food packaging, and beverage containers, adding to pollution.

- **Net preparation and mending activities:** Discarded plastic fragments from net mending and repair activities add to ALDFG accumulation onshore. Despite its significance, this source remains largely unaddressed in management efforts.

The movement of marine litter is further influenced by environmental factors such as coastal currents, wind patterns, and seasonal monsoon conditions. Lightweight items tend to accumulate on the leeward side of coastal structures, while heavier debris settles in near shore areas. As this survey represents a snapshot of marine debris abundance, litter distribution is expected to fluctuate over time due to dynamic environmental conditions.

7.4.2. Causes of ALDFG

The accumulation of ALDFG due to marine capture fisheries arises from both intentional and unintentional factors. Key causes include:

- **Gear type and fishing methods:** Certain fishing gear, particularly gillnets and trawl nets, have a higher likelihood of being lost or abandoned due to entanglement or damage.

- **Adverse weather conditions:** Storms, strong currents, and high winds can cause fishing gear to drift away, making recovery difficult.

- **Accidental loss:** Fishing nets and ropes may become entangled on underwater structures, leading to unintentional loss.

- **Inadequate disposal facilities:** Poor disposal practices of fishing nets and gear result in ALDFG. The lack of designated collection points for end-of-life fishing gear often induces fishermen to discard old or damaged gear directly into the ocean, which continues to threaten marine life.

- **User conflicts:** In zones with overlapping fishing activities, gear loss is common due to vessel collisions, unauthorized encroachments, and territorial disputes.

- **Illegal and unregulated fishing:** Some fishers intentionally abandon gear to avoid detection by authorities enforcing fishing regulations.

- **Ocean currents and transboundary transport:** ALDFG can drift long distances due to ocean currents, dispersing pollution beyond its original point of loss.

Understanding the root causes of ALDFG is critical for developing effective mitigation measures. To gain further insights, interviews were conducted with fishermen, and the results of the interview survey are discussed in Section 8.

7.5. Impacts of beach litter

Marine litter, particularly ALDFG, poses a significant threat to marine and coastal ecosystems. These materials persist in the marine environment for decades, damaging habitats, entangling marine organisms, and introducing microplastics into the food chain. Numerous studies have highlighted the detrimental impacts of ALDFG on marine biodiversity, including fish, seabirds, turtles, and marine mammals (Râpă et al., 2024). One of the most harmful effects is ghost fishing, where lost or abandoned nets continue to trap and kill marine life indefinitely and indiscriminately (Do et al., 2023).

In India, ALDFG has emerged as a major driver of biodiversity loss (Gunasekaran et al., 2024). The

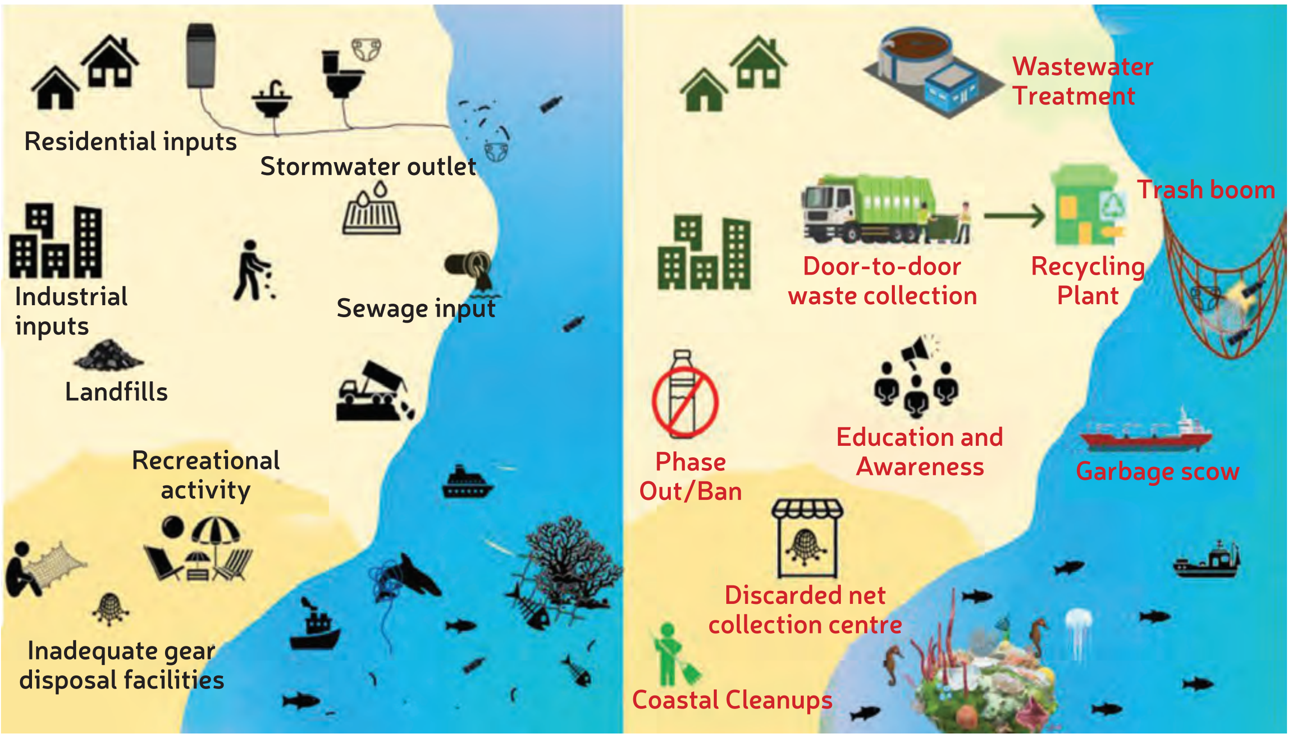


Fig. 7.16: Marine litter pollution: sources and solutions

increasingly reported entanglement incidents involving sea turtles, dolphins, and commercially valuable fish species pose a threat to both marine ecosystems and local fisheries (Kasa et al., 2025). Additionally, discarded nets and synthetic debris contribute to habitat degradation, particularly in coral reefs and seagrass ecosystems, which serve as critical breeding and feeding grounds for marine species (Mishra et al., 2022). The accumulation of fishing-related debris in these sensitive areas leads to physical damage, reduced habitat quality, and disruption of ecological balance.

Beyond ecological impacts, ALDFG and other beach litter also affect coastal economies and human health. The presence of plastic waste on beaches degrades the aesthetic value of coastal environments, negatively impacting tourism-dependent communities. Furthermore, microplastics from degraded fishing gear enter the marine food web, raising concerns about seafood safety and potential human health risks. Recognizing these challenges, global initiatives such as the Global Ghost Gear Initiative (GGGI) and UNEP's marine litter action plans aim to mitigate the threats posed by ALDFG through gear recovery programs, improved waste management, and the promotion of biodegradable fishing materials. However, despite these efforts, ALDFG remains a persistent issue, emphasizing the need for stronger regional policies, better enforcement mechanisms, and enhanced collaboration between fisheries, policymakers, and environmental organizations.

Addressing ALDFG is not only crucial for preserving marine biodiversity but also for ensuring the long-term sustainability of fisheries and the resilience of coastal ecosystems. Effective intervention strategies, including incentivizing responsible disposal, promoting gear marking systems, and implementing retrieval programs, can significantly reduce the long-term ecological and socio-economic consequences of ALDFG.

7.6. Solutions to beach litter pollution

To address the issue, several mitigation strategies are highlighted:

- **Wastewater treatment:** Properly treating wastewater reduces the influx of plastic particles and other pollutants into the marine ecosystem.

- **Door-to-door waste collection & recycling:** Strengthening the waste management systems ensures that waste is collected and processed and not allowed to enter water bodies.

- **Trash booms & garbage scows:** Floating barriers trap waste before it drifts into the ocean, while garbage scows (waste-collecting vessels) remove debris from the water.

- **Phasing-out/Banning Single-Use plastics:** Implementing policies to restrict harmful plastic products can significantly reduce pollution.

- **Education and awareness:** Public engagement and awareness campaigns play a vital role in promoting responsible waste disposal and environmental stewardship (Fig.7.16).

- **Discarded net collection centers:** Establishing collection hubs for end-of-life fishing gear can prevent ALDFG from accumulating in marine environments.

- **Coastal clean-ups:** Regular clean-up drives help remove existing waste and prevent further pollution.

Implementing these solutions and promoting sustainable waste management practices will contribute to a cleaner and healthier marine environment.

8

FAO FISHER SURVEY ON CAUSES AND RATES OF ALDFG PRODUCTION

8. FAO FISHER SURVEY ON CAUSES AND RATES OF ALDFG PRODUCTION

Over the past decade, there has been growing recognition of the urgent need to address the ecological and socioeconomic impacts of abandoned, lost, and discarded fishing gear (ALDFG). Despite this awareness, a significant knowledge gap remains regarding the life cycle of fishing gear, its end-of-life management, and the trends in ALDFG entering the oceans. Understanding fishery- and gear-specific factors influencing ALDFG generation, such as its rates, causes, and magnitude, is crucial for developing targeted mitigation strategies. To bridge this gap, a comprehensive fisherfolk survey was conducted across 52 fishing villages along the Tamil Nadu coast, using a structured questionnaire datasheet based on the FAO Global ALDFG Survey. This survey was designed by the Technology and Operation Team within FAO, in collaboration with regional stakeholders, to systematically assess ALDFG generation and management practices.

In response to the recommendations of the Committee on Fisheries (COFI), FAO has been working to enhance data collection efforts on ALDFG. The FAO Fishing Technology and Operations Team (NFIFO), under the Fisheries and Aquaculture Division, has developed standardized fisher survey forms and established a centralized portal to aggregate global ALDFG data. These surveys aim to provide robust regional and global analyses of ALDFG production, guiding informed policy decisions and sustainable fisheries management. The workflow for implementing the FAO Global ALDFG Survey follows a structured methodology, ensuring data consistency and reliability. A key aspect of the survey is the use of statistical models, such as the Bootstrap Method (Efron and Tibshirani, 1994), to generate accurate estimates of annual ALDFG rates. The collected data is entered into FAO's online database (https://fgla.fao.org/), enabling international comparisons and data-driven solutions for reducing marine litter.

8.1. Fisherfolk understands of marine litter

The fisherfolk questionnaire survey, conducted from January to June 2024, involved face-to-face interviews with local fishers at each sampling site along the Tamil Nadu coast. This survey sought to gain first-hand insights into the challenges, practices, and perceptions of fisherfolk regarding ALDFG.

Key insights from the survey include:

- **Awareness and attitudes:** Fisherfolk generally acknowledge the environmental and economic consequences of ALDFG but face constraints in adopting sustainable disposal and recovery practices.

- **Causes of gear loss:** Gear loss occurs due to a combination of environmental factors (e.g., rough seas, strong currents), operational challenges (e.g., gear conflicts, entanglements), and economic constraints (e.g., high retrieval costs).

- **Disposal and recovery practices:** While some fishers attempt to recover lost gear, the lack of proper disposal infrastructure leads to unintentional dumping. In certain cases, end-of-life fishing gear is abandoned due to financial and logistical constraints.

- **Challenges in gear management:** The absence of designated collection points for old or damaged gear, combined with limited awareness of recycling options, contributes to the persistence of ALDFG in marine environments.

The FAO ALDFG fisher survey program plays a crucial role in documenting and analyzing these insights. Aggregating ALDFG data at regional and global levels provides valuable information on gear-specific causes, rates, and magnitudes of ALDFG production. This data-driven approach supports the development of effective intervention strategies to mitigate the impact of ALDFG on marine ecosystems.

8.1.1.Overview of the fisherfolk survey in India under the FAO Global ALDFG Initiative

A fisherfolk survey was conducted in India as part of the FAO Global ALDFG Survey to assess the causes, rates, and management of ALDFG. Between January and June 2024, a total number of 470 fishersfrom 52 fishing villages along the Tamil Nadu coastwere interviewed using a structured questionnaire. The survey collected data on fishing gear types, fleet sizes, fisher demographics, and fishing ground preferences.

8.1.2. Surveyed fishing gear types and fleet size

The survey covered multiple fishing gear types and estimated the number of vessels (Table 8.1), and the details are given below:

Table 8.1. Details of surveyed fishing gear types and estimated number of vessels

Gear Type	Number of Vessels
Surrounding Nets	4,884
Seine Nets	4,082
Trawls	5,278
Gillnets & Entangling Nets	23,639
Traps & Pots	707
Hooks & Lines	4,765

8.1.3. Demographics of surveyed fishers

- **Age distribution & experience:** The age of the surveyed fisherfolk varied from under 20 to over 75 years and their fishing experience varied from less than one year to over 21 years.

- **Job titles:** Fishers were categorized by job roles across different gear types, including captain/skipper (61.43%), first-mate of boats (37.67%), deckhand (0.67%) and others positions (0.22%).

- **Vessel size classification:** Based on FAO categories, fishers operated vessels of three size classes: smaller vessels (<12 meters,77.13%), medium-sized vessels (12-24 meters, 22.20%) or larger vessels (>24 meters, 0.67%).

The classification of fishing gear types follows the International Standard Statistical Classification of Fishing Gear (FAO, 2016;He et al., 2021).

8.1.4. Fishing ground preferences
Fishers ranked their most frequently used fishing zones based on FAO-defined Exclusive Economic Zones (EEZ) and High Seas.

8.2. Fisherfolk questionnaire survey on the assessment of ALDFG magnitude

Estimating the magnitude of ALDFG is complex, requiring multiple approaches. Survey participants were asked to estimate the amount of synthetic material from fishing gear contributing to ALDFG annually, as well as the number of entire fishing gear units lost or discarded. To provide context, they also estimated the weight of a single gear unit. However, data inconsistencies can arise due to misinterpretation of questions, overestimation, or human errors in recording, leading to outliers that may affect results. These outliers can stem from various sources, making it essential to analyze data distribution and assess their impact on overall estimates.

Addressing these challenges helps improve data accuracy and supports more reliable estimations of ALDFG, contributing to better informed strategies for mitigating its environmental impact.

8.3. Analysis of ALDFG data distribution

Examining the distribution of ALDFG estimates for specific fishing gear types involved three types of visual analysis. First, violin plots (Fig. 8.1) were used to represent data density, incorporating elements of both boxplots and line plots, with outliers distinctly highlighted.

Next, a standard boxplot (Fig. 8.2) identified outliers as black points, while the median was marked by a vertical line through the box, encapsulating the inter-quartile range (25% to 75%) and extending whiskers to the minimum and maximum data points.

Finally, an unconventional boxplot (Fig. 8.3)

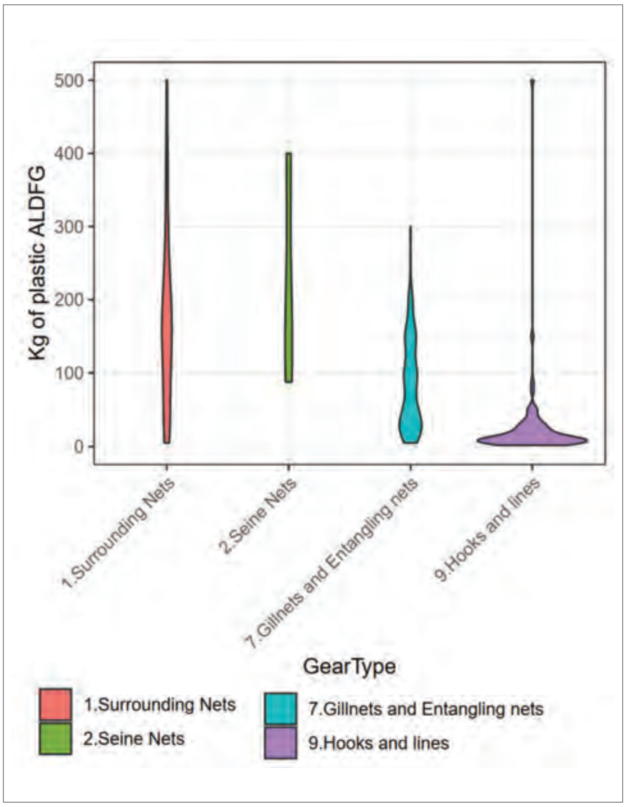


Fig. 8.1: Violin plot of estimated ALDFG weight by fishing gear type

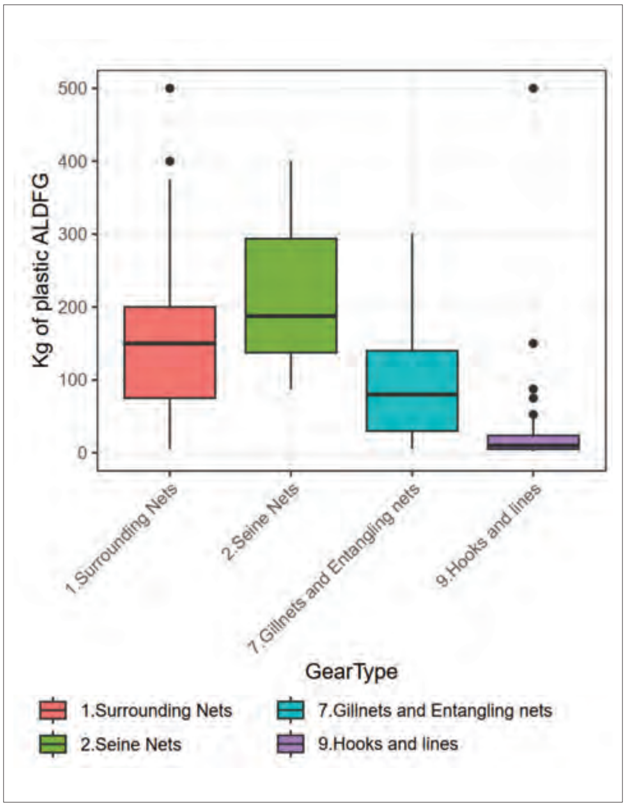


Fig.8.2: Box plot of ALDFG weight distribution across different fishing gear types

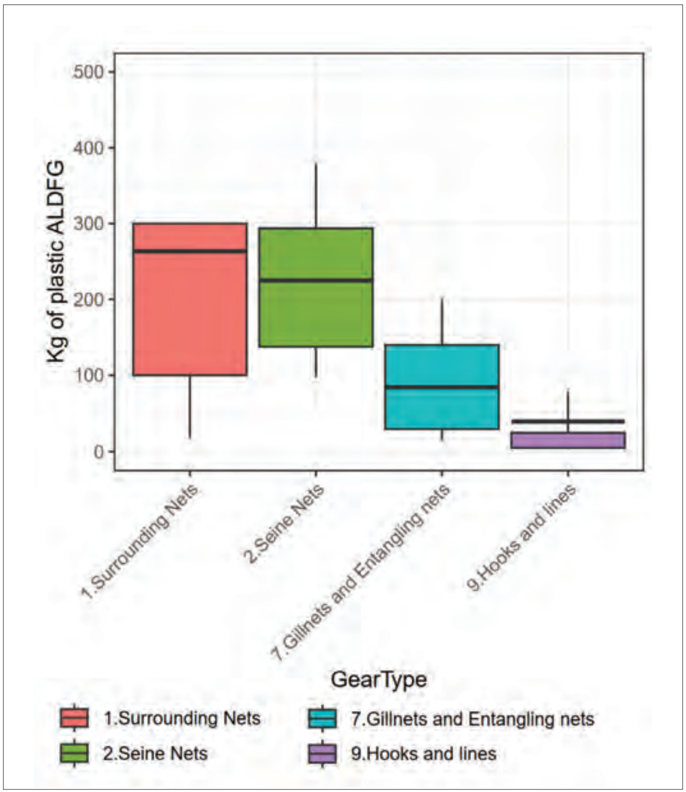


Fig.8.3. Box plot showing ALDFG weight distribution by fishing gear type with mean values

illustrated the relative distribution of ALDFG estimates, where the horizontal line represented the mean, and the box enclosed approximately 50% of the data. Since the mean ALDFG weight is highly sensitive to outliers especially those far from the central distribution gear types, exhibiting extreme values required careful interpretation.

Given the complexity of estimating ALDFG quantities, the survey recorded both the estimated synthetic material contribution and the number of entire gear units lost or discarded. However, data inconsistencies due to misinterpretation, overestimation, or recording errors introduced outliers that needed assessment. To address these issues, the Bootstrap Method (Efron and Tibshirani, 1994) was applied, mitigating the influence of outliers and providing robust statistical estimates of ALDFG magnitude. This approach enhanced the reliability of annual ALDFG estimates while accommodating the variability inherent in fisherfolk-reported data.

8.4. Direct and model-based estimation of ALDFG magnitude

8.4.1 Direct estimation

Table 8.2 presents the estimated annual mean ALDFG (in tons), extrapolated on the basis of the total number of registered vessels for each fishing gear type in Tamil Nadu. These estimates were derived from survey data collected from a subset of vessels and factored using the mean ALDFG per vessel, along with the corresponding upper and lower confidence intervals (CI). It is important to note that both the mean and confidence intervals are influenced by outliers, necessitating cautious interpretation. Estimates should not be interpreted as precise quantities, but rather as indicative ranges, reflecting the limitations of the survey. The total estimated annual production of ALDFG across all fisheries surveyed, including all registered fishing gear types in Tamil Nadu, is approximately 4,428 tons. However, the 95% confidence interval ranges from 1,128 to 7,728 tons, reflecting variability in the reported data and potential outliers.

Table 8.2. Annual mean estimates of ALDFG (in tons) with Confidence Intervals (CI)

Gear Type	Total Number of Registered Vessels in Tamil Nadu	Number of Fishers From vessels Sampled /Interviewed	Mean (tons)	Lower CI	Upper CI
Surrounding Nets	4,884	33 (27)	1,324	88	4,884
Seine Nets	4,082	5 (5)	918	398	1,546
Gillnets and Entangling Nets	23,639	328 (300)	1,996	355	4,728
Hooks and Lines	4,765	80 (68)	190	24	372
Total	37,370	446 (400)	4,428	1,128	7,728

8.4.2. Model-based estimation using the Bootstrap Method

To refine these estimates and minimize the impact of outliers, the Bootstrap method was applied. In this procedure, survey responses were randomly selected 100 times, and resampling was repeated 10 times for each gear type, generating a total of 1,000 resampled datasets. New means and confidence intervals (CIs) were computed for each fishing gear type based on these resampled datasets. Although this method results in a narrower confidence interval, the mean remains influenced by outliers. Each iteration of the model yields slightly different ALDFG magnitude estimates, leading to variations in the final outcome. However, the bootstrap-derived means consistently fall within the confidence intervals of the direct estimates from Table 8.2, providing a more robust estimate of ALDFG magnitude.

Table 8.3 displays the extrapolated results (in tons) across the entire surveyed fleet, considering all vessels using the specified gear types. Using the bootstrap method, the estimated annual ALDFG generated by the fishery is approximately 4,554 tons, with a 95% confidence interval ranging from 3,726 to 5,382 tons. These findings highlight the significant contribution of Tamil Nadu's fisheries to marine litter and emphasize the importance of applying robust statistical tools to improve the accuracy of ALDFG estimates.

These refined estimates underscore the variability in ALDFG production across different fishing gear types and demonstrate the significance of using advanced statistical methods to enhance the reliability of marine litter assessments.

8.5. Causes and practices of ALDFG

The generation and accumulation of ALDFG in marine capture fisheries depends on various intentional and unintentional factors, which include gear type, fishing methods, adverse weather conditions, accidental loss, inadequate storage, user conflicts, and limited disposal facilities for end-of-life fishing gear. Conflicts often arise in fishing zones with weak regulatory oversight, while illegal and unregulated fishing activities frequently lead to intentional gear abandonment to evade detection. Ocean currents further exacerbate ALDFG dispersion, carrying gear far from its original location and underscoring the transboundary nature of the issue.

Given the significant variations in fishing gear operations, survey respondents were asked to rank potential causes and preventive practices using three response options: Always, Sometimes, and Never. Additional choices included Don't Know or Not Relevant. Figures (Fig. 8.4 – Fig. 8.7) present scatter plots of causes against practices, with risk levels rated from 1 to 3, where 1indicates the lowest risk. The Risk Level is determined by multiplying the risk values assigned to both causes and practices, yielding a range from 1 to 9, with 9 representing the highest risk. Minor points represent individual responses, randomly distributed around corresponding values, while the larger point indicates the mean score.

8.6. Key findings on ALDFG causes by gear type

8.6.1. Surrounding nets

For surrounding nets, the primary cause of ALDFG was snagging on underwater obstructions such as reefs, rocky areas, or shipwrecks.

Table 8.3. Annual mean ALDFG (in tons) estimated using the Bootstrap Method

Gear Type	Total Number of Registered Vessels	Number of Fishers Sampled (Interviewed)	Number of Vessels Sampled	Mean (tons)	Lower CI	Upper CI	Median
Surrounding Nets	4,884	33 (27)	33	1,417	1,121	1,714	904
Seine Nets	4,082	5 (5)	5	919	813	1,025	765
Gillnets and Entangling Nets	23,639	328 (300)	328	2,004	1,728	2,280	1,844
Hooks and Lines	4,765	80 (68)	80	214	64	363	54
Total	37,370	446 (400)	446	4,554	3,726	5,382	3,566

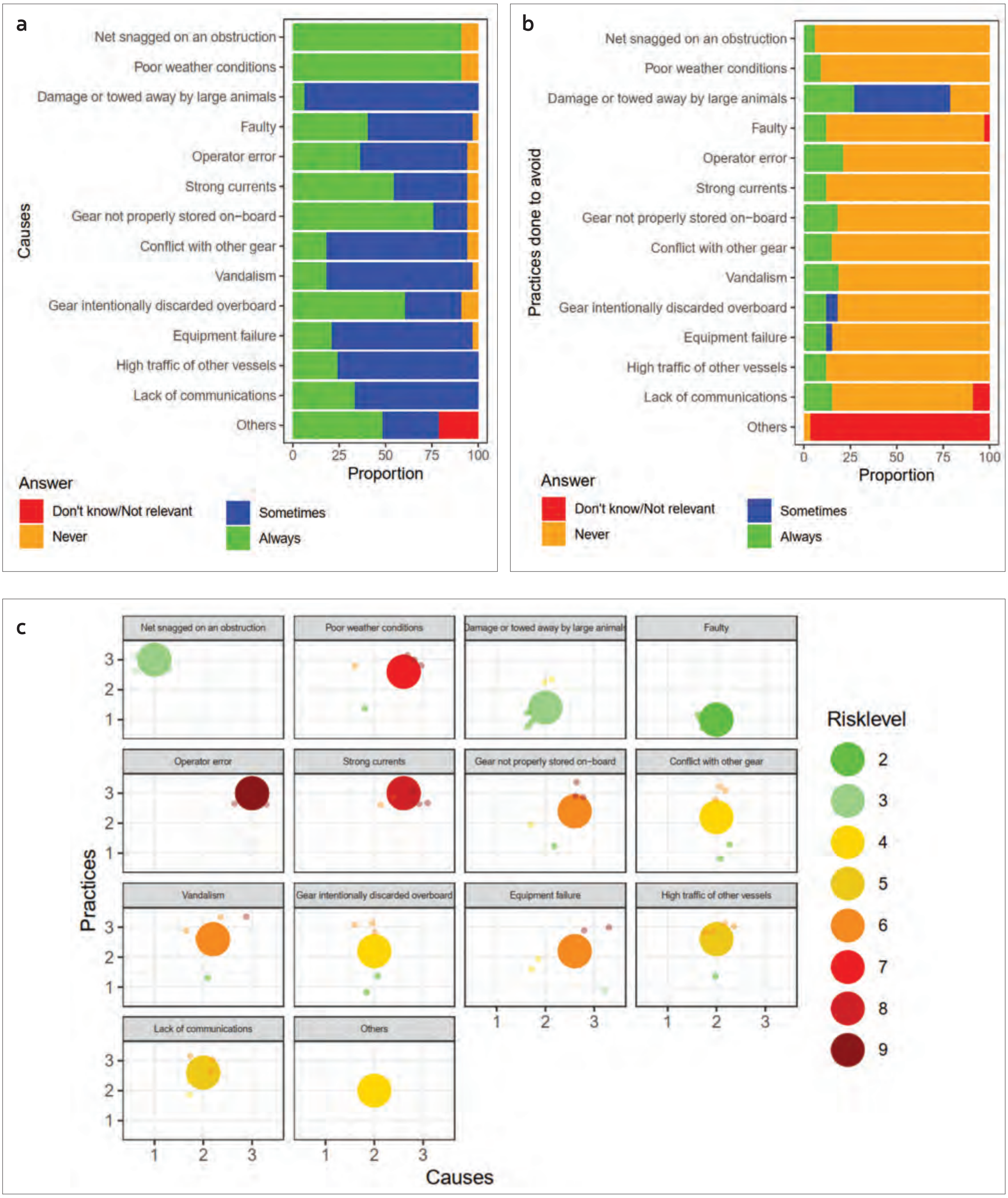


Fig. 8.4 a, b & c: The bar plot illustrates the distribution of responses regarding ALDFG causes (a) and preventive practices (b). Each scatter plot (c) visualizes causes against practices, depicting risk levels from 1 to 3. The Risk Level is derived by multiplying risk values from causes and practices, ranging from 1 to 9, with 9 indicating the highest risk. Minor points represent individual responses, while larger points indicate the mean score

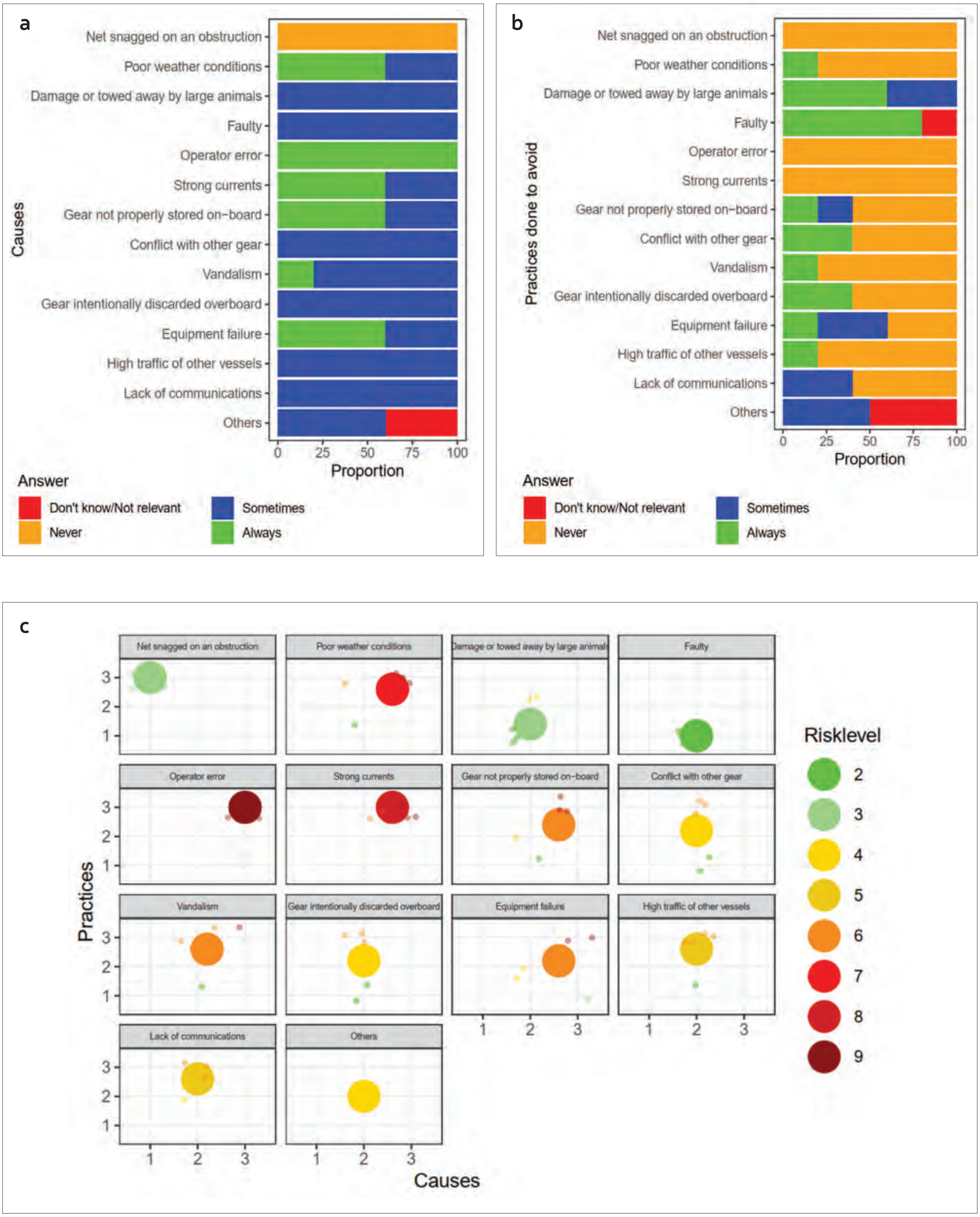


Fig. 8.5 a, b & c: Similar to Figure 8.4, this figure presents a bar plot and scatter plot distribution, categorizing ALDFG causes and associated practices for seine nets

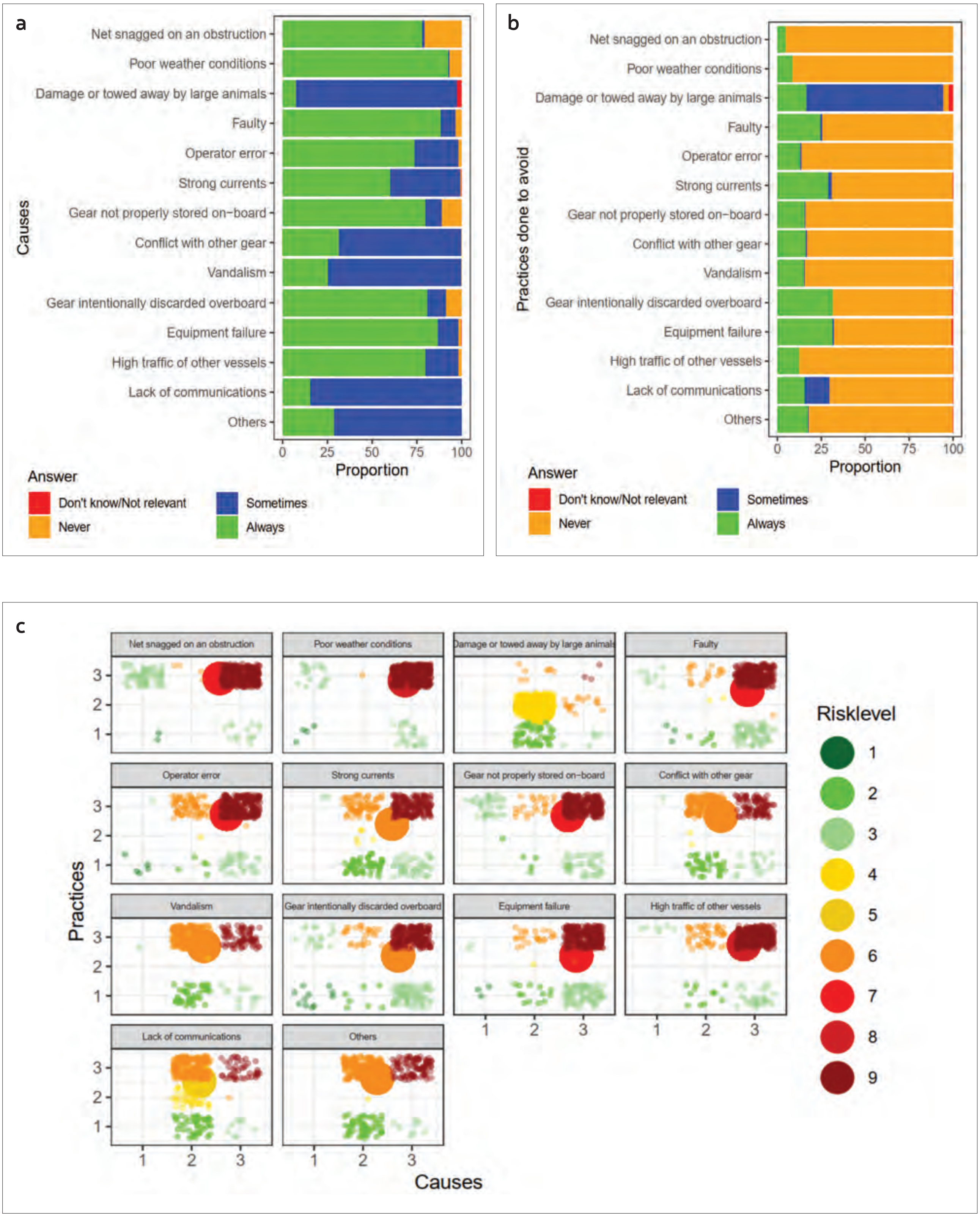


Fig. 8.6 a, b & c: This figure visualizes the relationship between ALDFG causes and practices for gillnets and entangling nets, using risk level categorization from 1 to 9

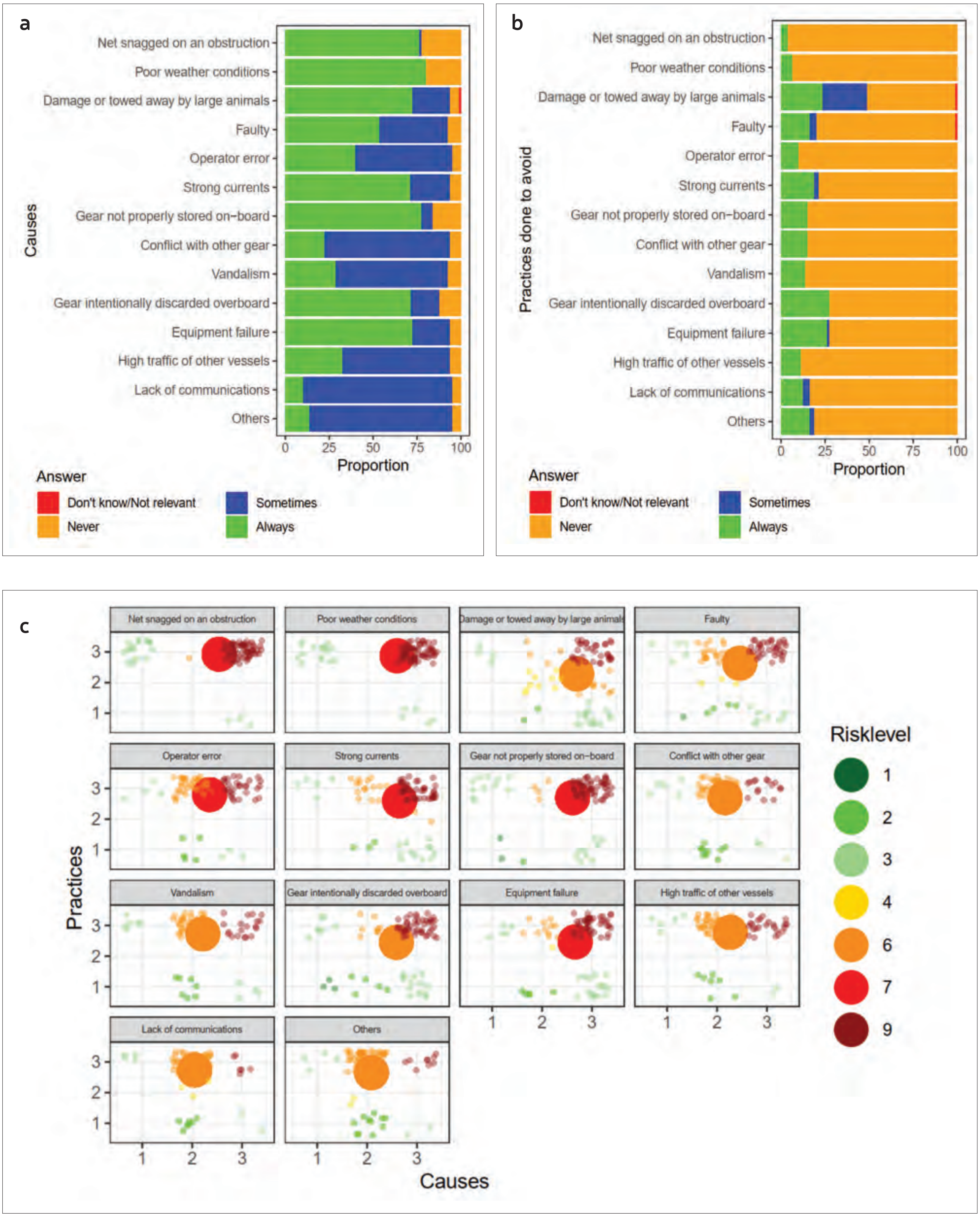


Fig. 8.7 a, b & c: This figure presents the same structured analysis for hooks and lines, illustrating the risk-based categorization of ALDFG causes and prevention strategies

8.6.2. Seine Nets

For seine nets, operator error was identified as the leading cause of ALDFG, particularly in cases of entanglement or improper handling during deployment and retrieval.

8.6.3. Gillnets and Entangling Nets

For gillnets and entangling nets, adverse weather conditions contributed most significantly to ALDFG losses, as rough seas often cause gear displacement or damage.

8.6.4. Hooks and Lines

For hooks and lines, adverse weather was the primary cause of ALDFG, particularly in small-scale fisheries where vessels and gear are more susceptible to environmental conditions.

8.7. Lack of disposal facilities

A significant 94.81% of interviewed fishers reported a lack of disposal facilities at or near their vessel's home port or landing site for end-of-life fishing gear. This limitation exacerbates the ALDFG issue, as fishers have no proper means to discard non-functional or damaged gear responsibly. These findings highlight the urgent need for enhanced waste management strategies, improved regulatory frameworks, and the promotion of responsible fishing practices to mitigate ALDFG impacts on marine ecosystems.

8.8. Conclusion

The FAO Global ALDFG fisher survey conducted along the Tamil Nadu coast offers valuable data on the rates, causes, and practices contributing to abandoned, lost, and discarded fishing gear. The findings indicate that gillnets and entangling nets are associated with the highest estimated ALDFG quantities, with adverse weather and gear snagging identified as key contributing factors. A substantial number of respondents also reported the absence of disposal facilities at landing sites, which further complicates end-of-life gear management. These insights contribute to FAO's global database, supporting regional and international comparisons and informing the development of standardized, data-driven mitigation strategies for ALDFG.

9

COASTAL HEALTH STATUS: BEACH QUALITY INDEXES

9. COASTAL HEALTH STATUS: BEACH QUALITY INDEXES

Clean beaches are key indicators of a country's environmental health and commitment to sustainable development. Various sustainability indices have been developed to assess beach quality in order to ensure both ecological balance and aesthetic appeal. These indices not only help quantify and manage beach cleanliness but also aid in identifying sources of marine debris and evaluating the effectiveness of beach-cleaning initiatives. By integrating environmental conservation goals with regional interests, these indices support better coastal management and marine debris reduction. Beaches hold significant social and economic value as recreational and tourism hubs, making their protection crucial (Shasha et al., 2023). As a result, monitoring and regulating their environmental quality have become a priority for both the scientific community and the coastal zone managers.

Beach Quality Index (BQI) is an essential tool for assessing the environmental status of coastal areas. In this study, the following four key indices were used to evaluate the pollution levels found in the beaches of Tamil Nadu:

- Clean Coast Index (CCI) - measures overall beach cleanliness
- Clean Environment Index (CEI) - assesses the impact of various types of litter on the coastal environment
- Plastic Abundance Index (PAI) - quantifies the level of plastic pollution on beaches
- Hazardous Litter Index (HLI) - identifies and evaluates the distribution of hazardous waste

By employing these indices, the study categorized beaches based on their debris levels and provided comparative insights into pollution

patterns. The findings underscore the fact that marine debris is not just an environmental issue but also a social and public health concern. This assessment highlights the urgent need for targeted clean-up efforts and sustainable waste management strategies to improve the overall quality of coastal environments.

9.1. Beach Quality Indices methodology

9.1.1. Clean Coast Index (CCI)

The Clean Coast Index (CCI) was originally developed by Alkalay et al. (2007) to assess coastal cleanliness based on plastic litter accumulation. More recently, the index has been expanded to include all types of litter (Ilechukwu et al., 2024).

The CCI is calculated using the formula:

$$CCI = \frac{\sum \text{Litter Items}}{\text{Length (m)} \times \text{Width (m)}} \times K$$

Where **K** is a constant equal to 20

This index quantifies the number of litter items per square meter within a defined sampling unit, indicating beach cleanliness. It is used to determine whether a beach maintains or improves its cleanliness over time. The CCI classification system is as follows:

- **Very Clean** (0 – 2)
- **Clean** (2.1 – 5)
- **Moderately Clean** (5.1 – 10)
- **Dirty** (10.1 – 20)
- **Extremely Dirty** (> 20)

9.1.2. Clean Environment Index (CEI)

The Clean Environment Index (CEI) evaluates pollution levels on beaches and other environments by considering both the quantity and significance of different types of litter.

The CEI is calculated using the formula:

$$CCI = \frac{\sum (Wi \times Ni)}{\text{Length (m)} \times \text{Width (m)}} \times K$$

where:

- **Wi**= weight coefficient assigned to different litter types
- **Ni** = number of items of each litter type

The CEI classification system follows a similar scale to the CCI:

- A (Very Clean): 0 – 2
- B (Clean): 2 – 5
- C (Moderately Clean): 5 – 10
- D (Dirty): 10 – 20
- E (Extremely Dirty):> 20

This index is widely used to assess litter contamination in various environments, including urban areas, public spaces, and beaches.

9.1.3. Plastic Abundance Index (PAI)

The Plastic Abundance Index (PAI), proposed by Rangel-Buitrago et al. (2022), quantifies plastic pollution on beaches by measuring the proportion of plastic items relative to total litter.

The PAI is calculated using the formula:

$$PAI = \frac{\sum \text{Plastic litter items}}{\frac{\sum \text{Total litter items}}{\text{Area}}} \times 20$$

This formula accounts for the density of plastic items per square meter while considering the overall marine litter collected along the Tamil Nadu coast. The classification of plastic abundance is as follows:

- **Very Low Abundance:** 0
- **Low Abundance:** 0.1 – 1.0
- **Moderate Abundance:** 1.1 – 4.0
- **High Abundance:** 4.1 – 8.0
- **Very High Abundance:** > 8

This index is useful for tracking plastic pollution trends over time and identifying critical areas requiring intervention.

9.1.4. Hazardous Litter Index (HLI)

The Hazardous Litter Index (HLI) evaluates the presence of potentially harmful litter on beaches, such as sharp metal objects, broken glass, cigarette butts, sanitary waste, and medical debris. These materials pose risks to beachgoers and marine life.

The HLI is calculated using the formula (Rangel-Buitrago et al., 2020):

HLI = ((∑ *Hazardous litter items*/ log 10 ∑ *Total litter items*)/Area) x K

Where **K** is a constant

Beaches are classified based on the presence of hazardous litter:

- **I – No hazardous litter observed:** HLI = 0
- **II – Some hazardous litter across a large area:** HLI = 0.1 – 1
- **III – Considerable amount of hazardous litter:** HLI = 1.1 – 4
- **IV – Large quantities of hazardous litter present:** HLI = 4.1 – 8
- **V – Most of the beach is covered with hazardous litter:** HLI > 8

This index is essential for assessing public health risks associated with marine debris and guiding targeted clean-up initiatives.

9.2. Results

9.2.1. Clean Coast Index (CCI)

The Clean Coast Index (CCI) provides an objective and unbiased measure of beach cleanliness by assessing the amount of litter per unit area. It serves as a valuable tool for evaluating coastal pollution and monitoring the effectiveness of mitigation efforts such as awareness campaigns, media coverage, and enforcement actions. In this study, the highest CCI value was recorded in Villupuram district (CCI: 55.23), categorizing it as 'extremely dirty,' while the lowest was in Mayiladuthurai district (CCI: 6.15), indicating a 'moderately clean' status. Based on CCI classifications, 23% of the study area was moderately clean, 31% was dirty, and 46% was extremely dirty due to high litter accumulation (Fig.9.1).

The CCI analysis results for the 52 coastal sites along Tamil Nadu are presented in Fig.9.2. Notably, none of the surveyed beaches fell under the 'very clean' or 'clean' categories.

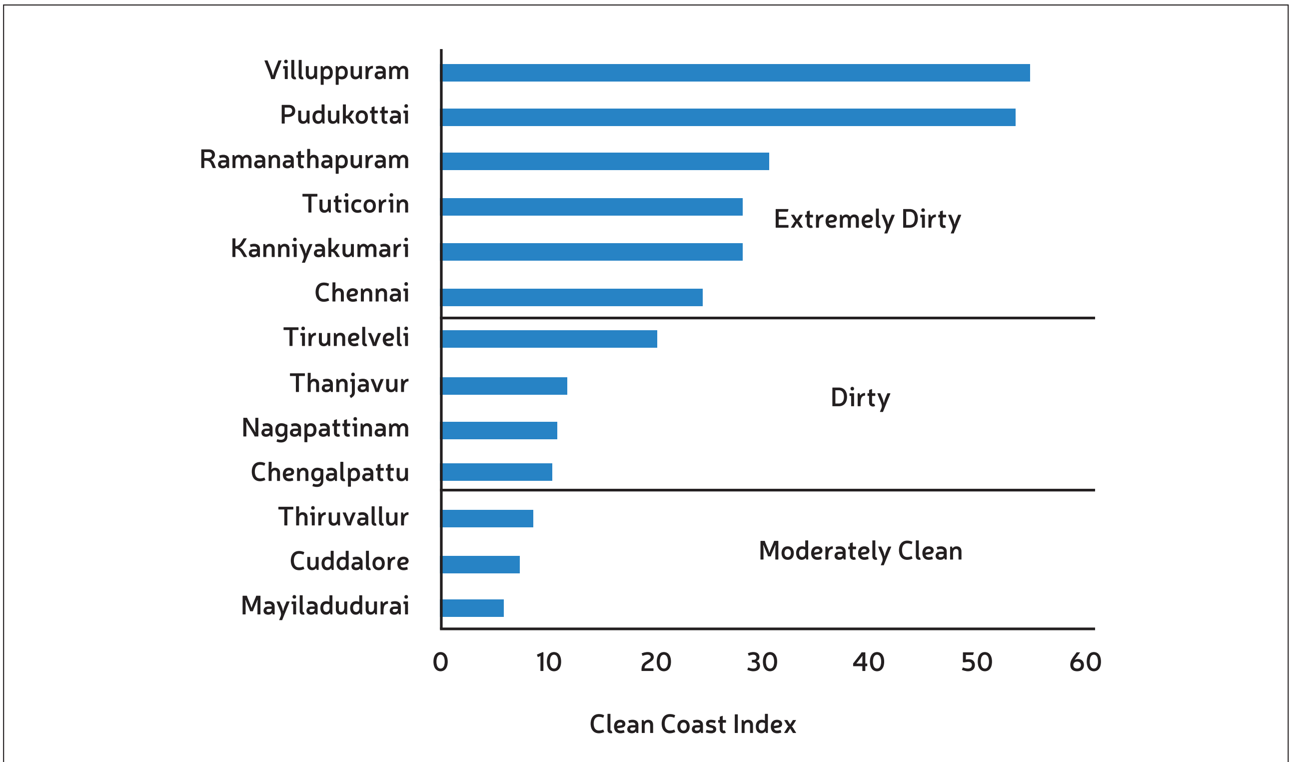


Fig.9.1: Clean Coast Index (CCI) analysis for coastal sites in 13 districts

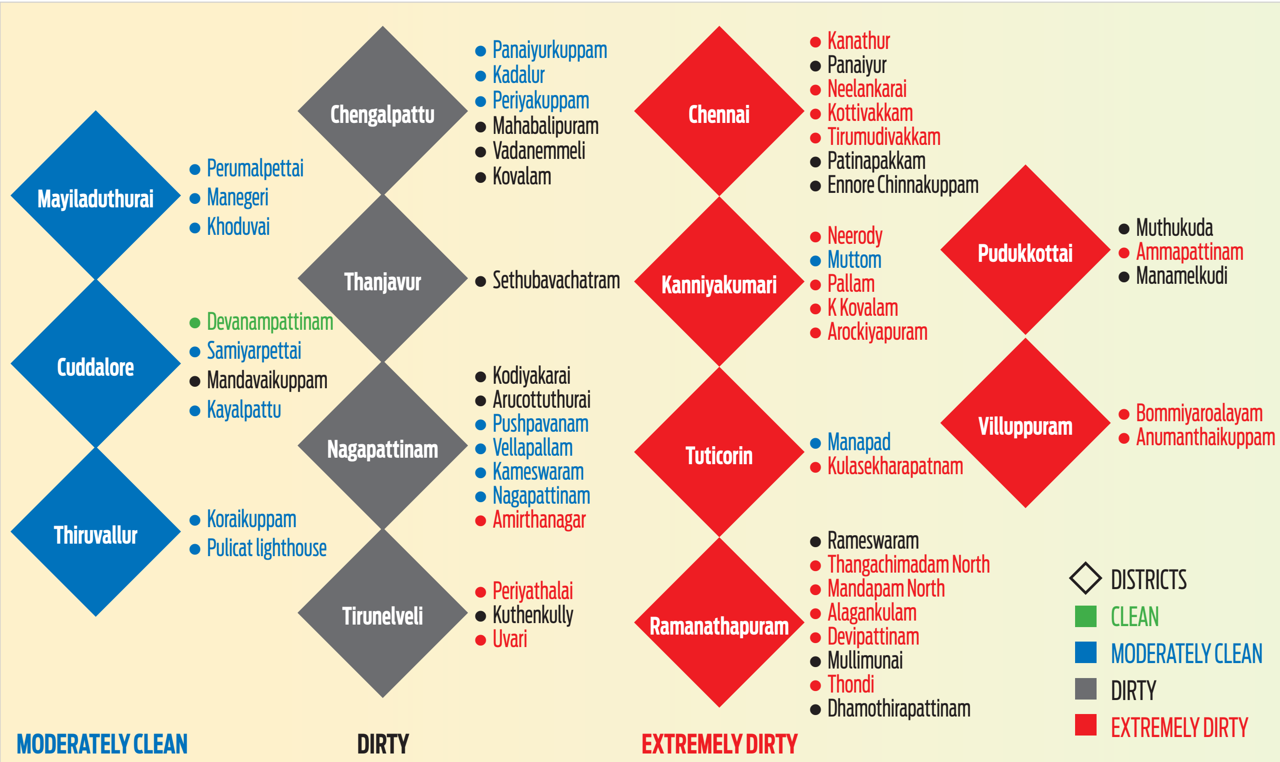


Fig.9.2: Clean Coast Index (CCI) analysis for 52 coastal sites in Tamil Nadu

These findings align with the results of studies from various regions, such as Nguyen et al. (2025), which assessed Vung Tau beaches in Southern Vietnam, where 16.7% of beaches were categorized as clean and 83.3% as moderate, with none classified as very clean. Similar low cleanliness levels were observed in northeast Indian beaches (Mugilarasan et al., 2021), Kanniyakumari beaches (CCI: 27.24) (Perumal et al., 2022), and Mumbai beaches (De et al., 2022). International studies in Indonesia (Cordova et al., 2022), Turkey (Ertaş, 2021), the Philippines (Paler et al., 2019), Brazil (Marin et al., 2019), Greece, Slovenia, Italy, and Montenegro (Vlachogianni et al., 2018), the Northeastern Mediterranean (Aydın et al., 2016), and Volano, north-western Adriatic (Munari et al., 2017) also reported similar results, highlighting significant litter accumulation. In contrast, beaches in Kerala (Kaladharan et al.,2017; Mugilarasan et al., 2023), Thondi coast in Palk Bay (Perumal et al., 2021), Chile (Rangel-Buitrago et al., 2020; Barría-Herrera et al., 2021), Morocco Mediterranean beaches (Nachite et al., 2019), Thailand (Horpet et al., 2020), and Albania (Fernández-Enríquez et al., 2024) were found to be clean or moderately clean. The CCI results highlight the urgent need for improved waste management and stricter pollution control measures to enhance the environmental quality of Tamil Nadu's coastal areas.

9.2.2. Clean Environment Index (CEI)

The Clean Environment Index (CEI) shares key similarities with the Clean Coast Index (CCI) but offers a more comprehensive assessment by incorporating a weighting factor (Wi) for each type of litter. This approach ensures a more accurate evaluation of pollution levels by considering not only the quantity of litter but also its associated environmental and health risks (Delavari Heravi et al., 2024). In this study, plastics accounted for approximately 87.1% of the total litter, emphasizing their dominance in terms of both volume and environmental impact. Recognizing the severity of plastic pollution, a weighting factor (Wi) of 1.5 was assigned to all plastic items to reflect their significant contribution to pollution levels.

The results for the Clean Environment Index (CEI) analysis for the 52 coastal sites along Tamil Nadu are presented in Figure 9.3. Among the districts assessed, Pudukottai recorded the highest CEI score, indicating severe pollution levels, whereas Cuddalore had the lowest, signifying relatively better conditions. The CEI classification revealed that 62% of the study area falls under the “extremely dirty” category, 23% is classified as “dirty” and only 15% is considered “moderate.” The high percentage of extremely dirty areas is likely due to the frequent disposal of persistent litter types that not only degrade slowly but also contribute to higher pollution emissions, further exacerbating environmental concerns.

These findings highlight the urgent need for effective waste management strategies to mitigate pollution and improve coastal cleanliness. Similar trends have been observed in previous studies; for instance, JonidiJafari et al. (2021) reported a moderate cleanliness status based on the CCI, whereas the CEI assessment of the same beaches indicated a “dirty” condition, reinforcing the necessity of using more refined indices for accurate pollution assessment.

9.2.3. Plastic Abundance Index (PAI)

The Plastic Abundance Index (PAI) was used to assess the intensity of plastic pollution and based on pollution severity the beaches were catego-

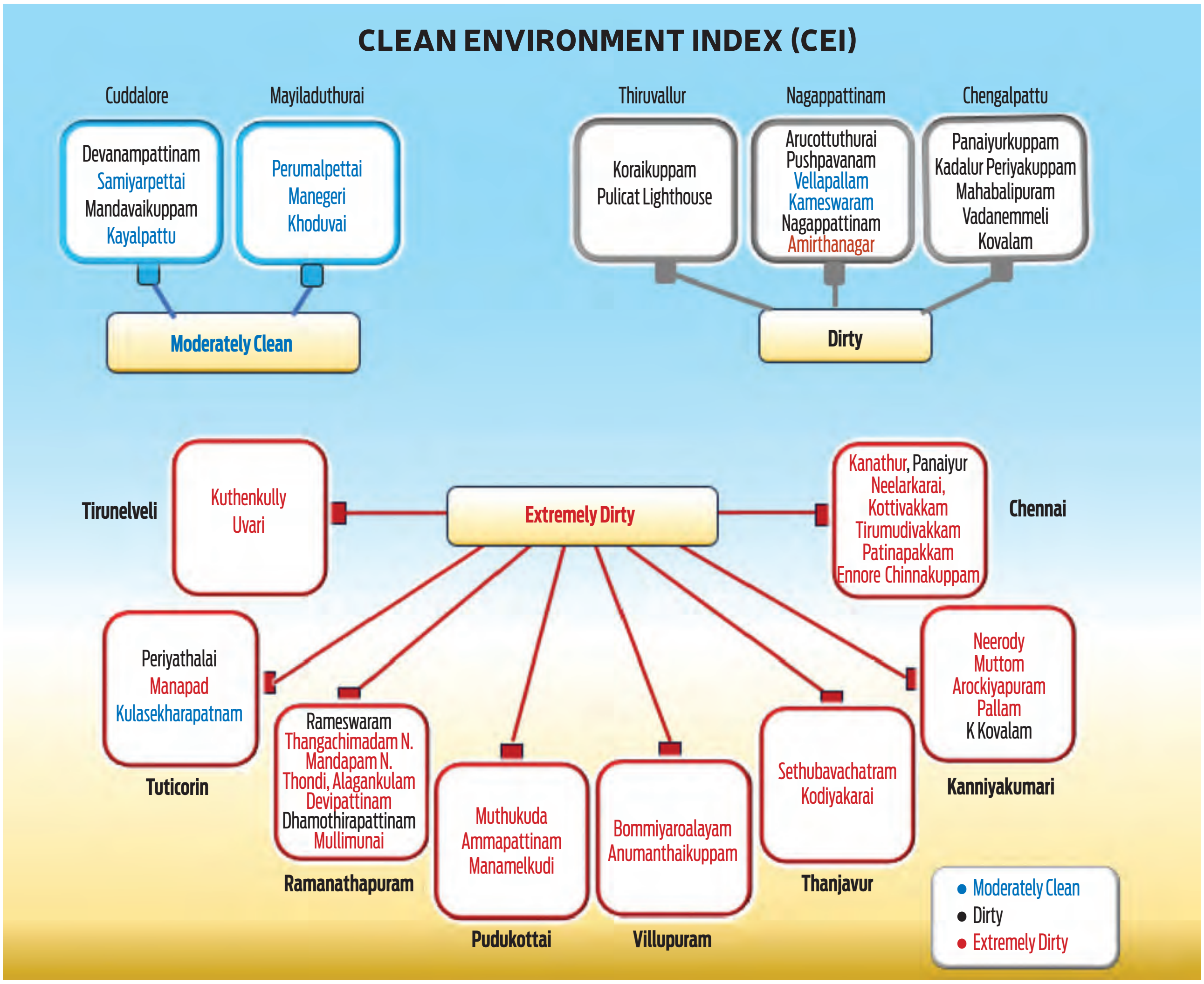


Fig.9.3: Clean Environment Index (CEI) analysis for 52 coastal sites in Tamil Nadu

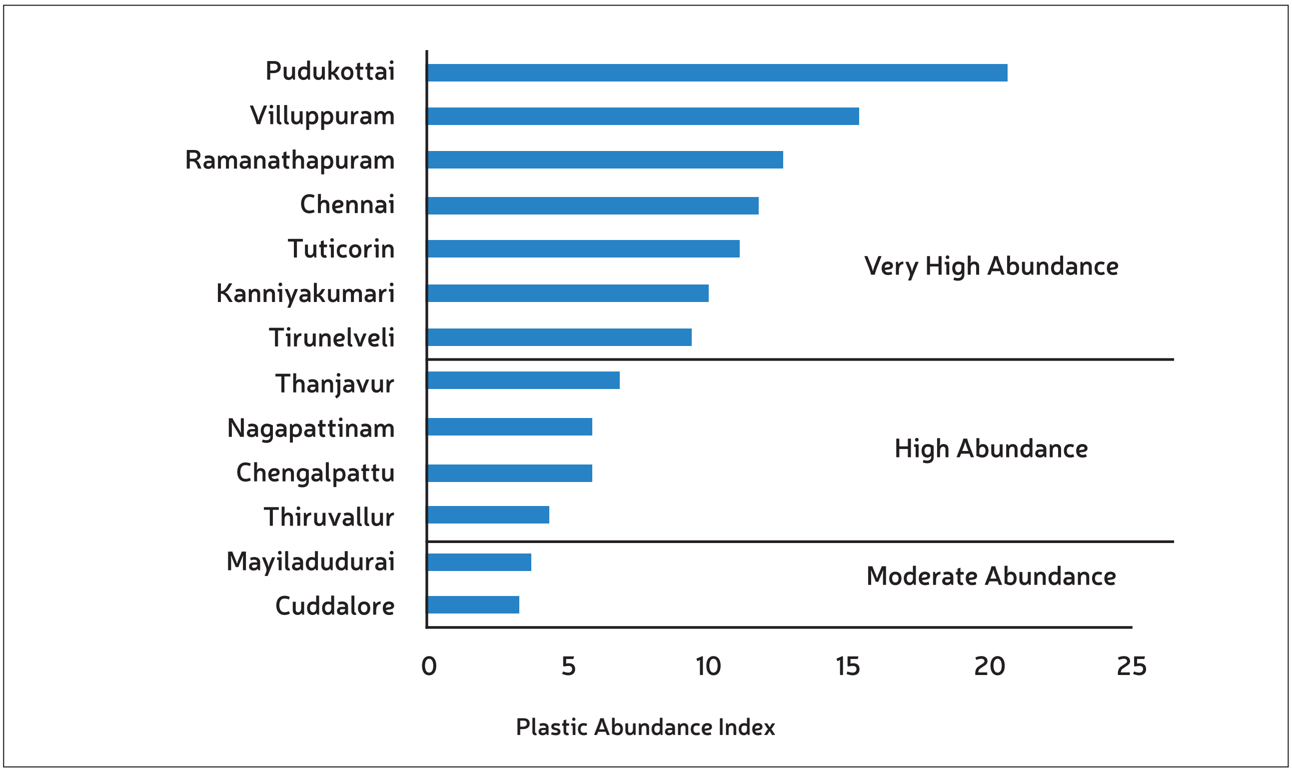


Fig.9.4: Plastic Abundance Index (PAI) analysis for coastal sites in Tamil Nadu

rized. The findings revealed that 39% of the assessed beaches exhibited a "very high abundance" of plastic waste, 46% were categorized as having "high abundance," and 15% showed "moderate abundance" (Fig.9.4). Notably, none of the beaches were classified under the "very low" or "no abundance" categories. The PAI analysis results for the 52 coastal sites along Tamil Nadu are presented in Fig. 9.5. The overall mean PAI was 9.3, falling within the "very high abundance" category. Among the districts, Pudukottai recorded the highest PAI (20.6), indicating very high plastic pollution levels, whereas Cuddalore had the lowest (3.3), signifying moderate abundance.

A comparative study by Al Nahian et al. (2022) on Saint Martin Island found that 24% of sites exhibited "very high plastic abundance," 33% had "high abundance," and another 33% showed "moderate abundance". Similarly, research from Southern India (Perumal et al., 2023) reported that 71.43% of the surveyed beaches exhibited high plastic abundance, further reinforcing the growing concern of marine plastic pollution in this region. The results of the present survey highlight that marine litter, particularly plastic waste, remains a significant human-driven threat, emphasizing the urgent need for targeted solid waste management and pollution mitigation strategies. Identifying contamination hotspots is essential for implementing effective litter management interventions. The distribution and composition of marine litter are primarily due to household, tourism, and fishing activities, underscoring the necessity for regional waste management improvements. To address this issue, recommended management practices include source reduction, pollution mitigation, sustainable beach environment management, and behavioural changes through environmental education. Additionally, adopting an Integrated Coastal Zone Management (ICZM) approach, supported by coordinated policy frameworks, can help mitigate the debris footprint in coastal environments, fostering sustainable marine ecosystem conservation.

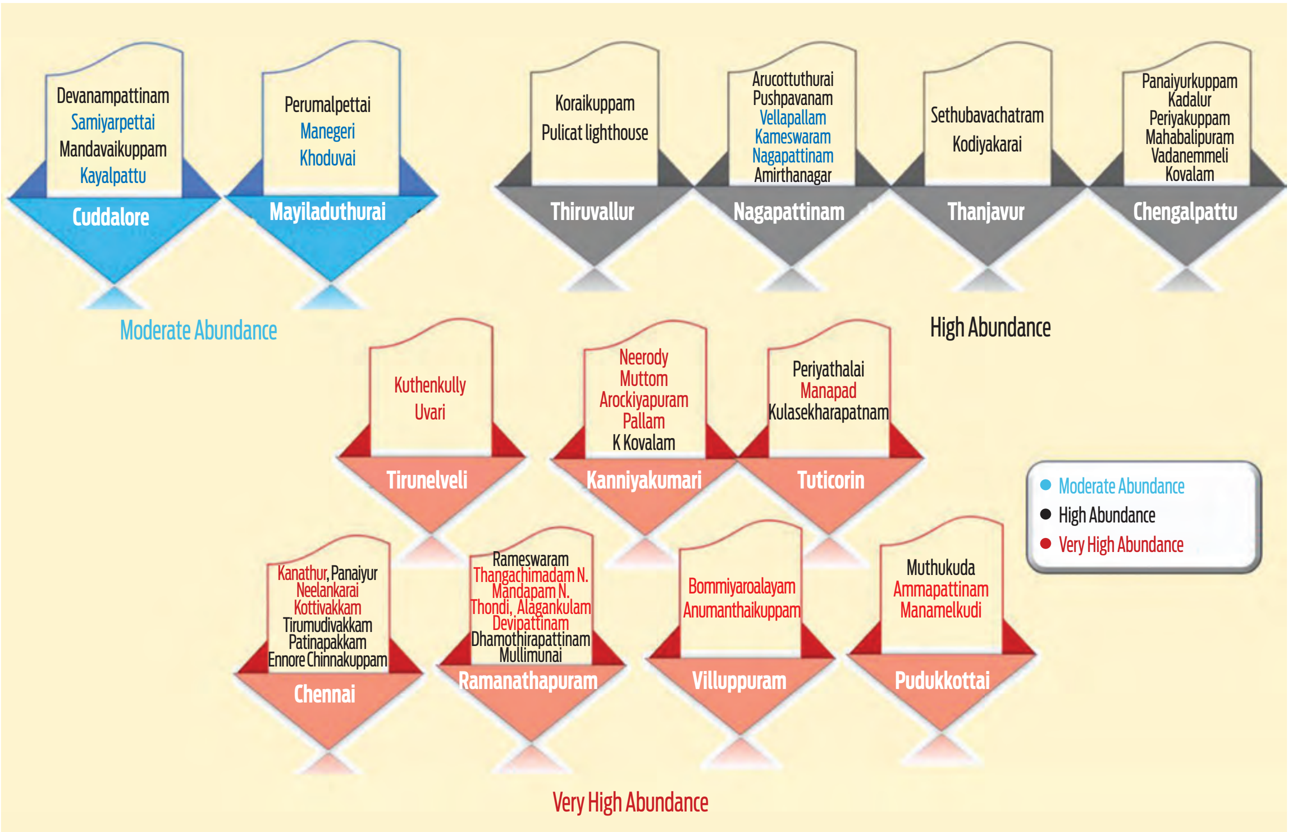


Fig.9.5: Plastic Abundance Index (PAI) analysis for 52 coastal sites in Tamil Nadu

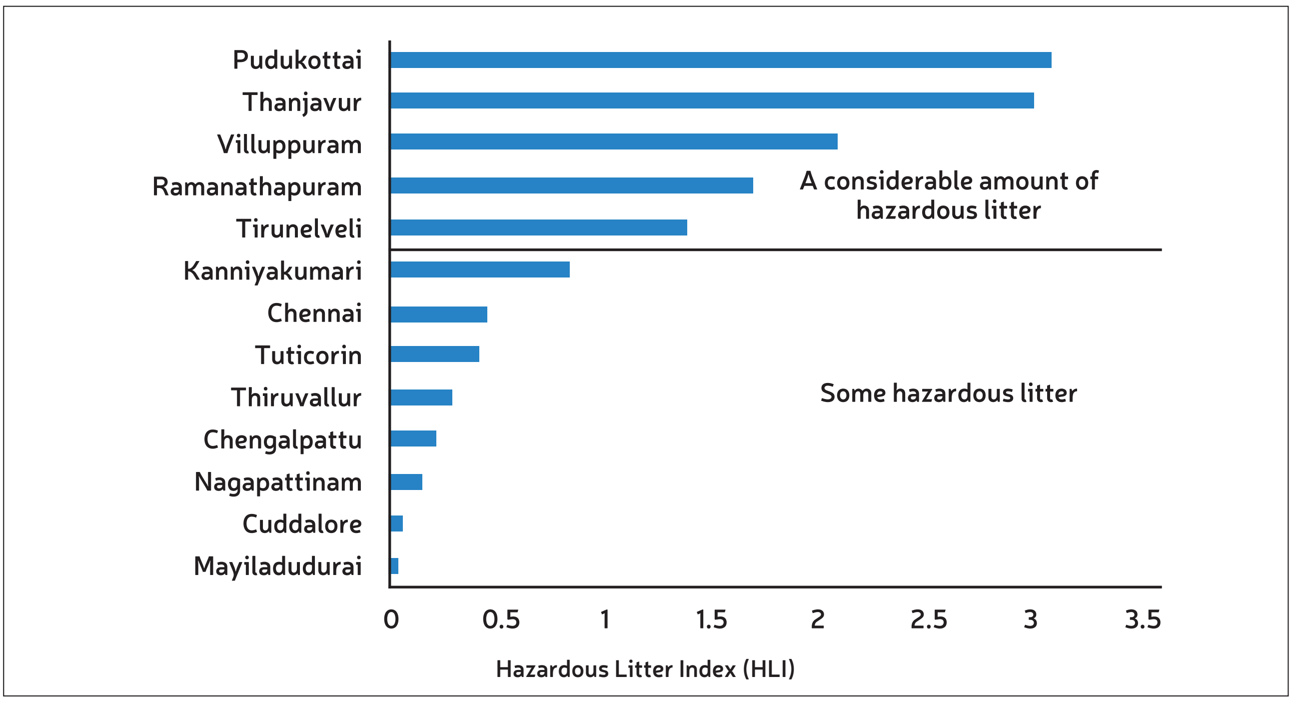


Fig.9.6: Hazardous Litter Index (HLI) analysis for coastal sites in Tamil Nadu

9.2.4. Hazardous Litter Index (HLI)

The presence of hazardous litter, particularly medical waste, sharp objects, and chemically contaminated debris, on coastal beaches poses serious risks to human health and the environment (Williams et al., 2017). In this study, 62% of the assessed beaches were categorised under Category II, indicating that hazardous litter is present over a large area, while 38% fell under Category III, signifying a considerable amount of hazardous waste (Fig. 9.6).

The HLI analysis results for the 52 coastal sites along Tamil Nadu are presented in Figure 9.7. Among the districts, Pudukottai recorded the highest HLI (3.08), while Mayiladuthurai had the lowest (0.03), highlighting regional disparities in hazardous litter accumulation. Comparatively, Shankar et al. (2024) reported slightly lower HLI values in the Andaman and Nicobar Islands (Category II), indicating a moderate presence of hazardous litter. In contrast, Sandaruwan et al. (2023) documented higher HLI values in Kandakuliya and Kalpitiya in Sri Lanka (Category IV), suggesting a severe presence of hazardous waste in that region. Similarly, a study by Mghili (2023) on Moroccan beaches found that hazardous litter items accounted for 8.41% of total collected debris, with a mean density of 0.026 items/m^2.

These findings emphasize that poor waste management remains a major contributor to hazardous litter pollution along coastal areas. Addressing this issue requires effective waste disposal strategies, enhanced monitoring programs, and stricter regulatory enforcement to mitigate the environmental and health risks associated with hazardous debris.

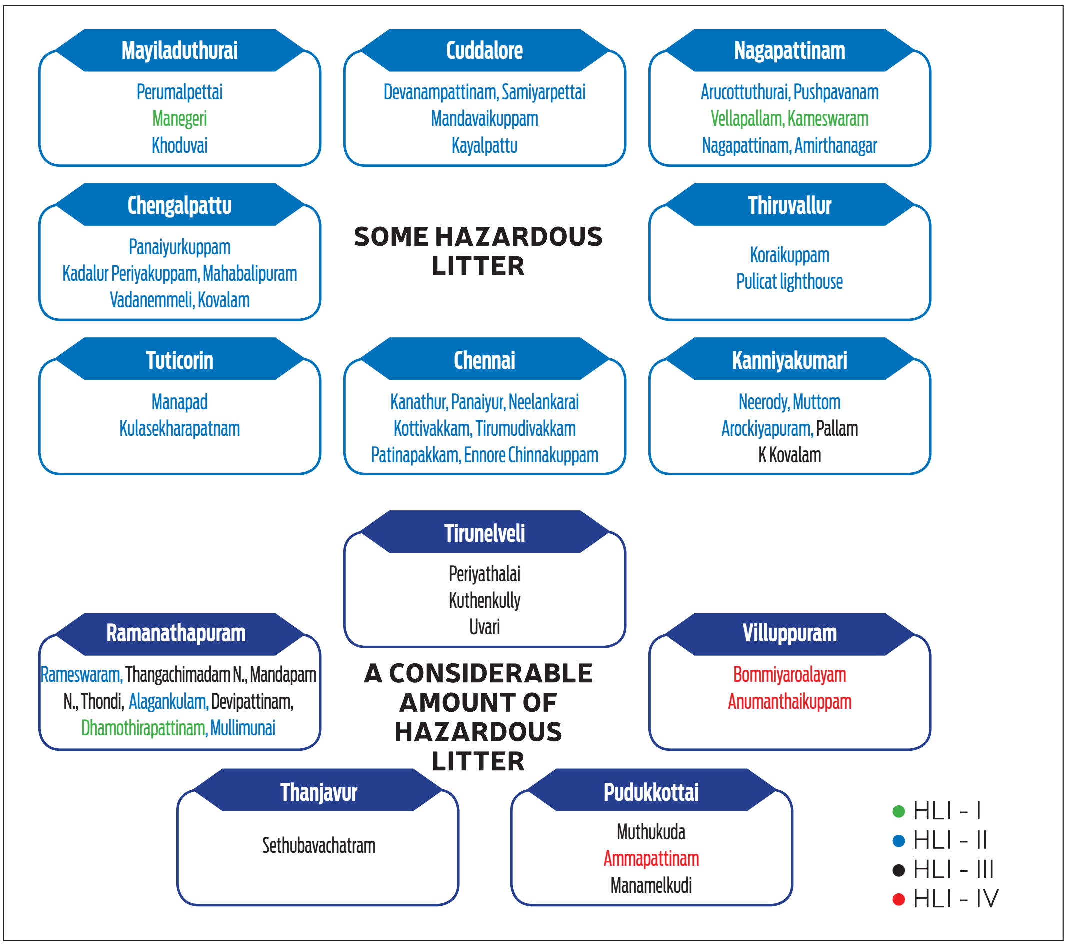


Fig.9.7: Hazardous Litter Index (HLI) analysis for 52 coastal sites in Tamil Nadu

10

ASSESSMENT OF MARINE LITTER ORIGINATING FROM FISHERIES IN THE GULF OF MANNAR (MARESSOL REPORT)

10. ASSESSMENT OF MARINE LITTER ORIGINATING FROM FISHERIES IN THE GULF OF MANNAR (MARESSOL REPORT)

10.1.Back ground

The Gulf of Mannar (GoM) is an ecologically rich marine environment along the southeastern coast of India, supporting high biodiversity, and sensitive marine ecosystems. Despite its ecological value, the region faces increasing pressures from overexploitation of marine resources, destructive fishing methods, and pollution especially plastic pollution originating from fisheries (Patterson Edward et al., 2020).

10.2. Baseline survey and research initiatives

This report is part of the 'Mannar Region Systemic Solutions (MARESSOL)' project—an international partnership between SALT (Norway), the Suganthi Devadason Marine Research Institute (SDMRI) in India, the Lanka Environment Fund, and the International Union for Conservation of Nature (IUCN) in Sri Lanka. The project, funded by the Norwegian Retailers' Environment Fund, was carried out from 2021 to 2024. It adopted a cross-disciplinary approach, integrating scientific research, building awareness and policy advisory efforts.

The primary objective of MARESSOL is to reduce marine plastic pollution from fisheries in the Gulf of Mannar and the southern section of the Palk Bay by implementing structured and targeted interventions. This includes addressing the issue of ALDFG and promoting sustainable fishing practices to reduce marine litter. On the Indian side, a baseline survey was conducted during both the summer and monsoon seasons of 2021 and 2022 across 12 fishing villages in the Gulf of

Mannar. While the broader MARESSOL study—documented in the report "Marine Litter from Fisheries in the Gulf of Mannar and Palk Strait: Knowledge Basis and Recommended Avenues for Change"—covered 17 sites (12 in India and 5 in Sri Lanka), this technical report presents findings only from the 12 Indian sites (MARESSOL, 2022). These findings provide critical insights into the sources, composition, and impacts of fisheries-related marine litter, and serve as a foundation for formulating effective management strategies and policy recommendations to curb plastic pollution in this ecologically sensitive region.

10.3. Objectives

The project aimed to quantify ALDFG through:

- Shoreline litter sampling
- FTIR analysis of beach litter
- Assessment of solid waste dumping areas
- Fishermen survey on ALDFG

10.4. Study region

The study covered a total of 12 locations along the Indian side of GoM, 7 sites in Tuticorin district and 5 sites in Ramanathapuram district, spanning from Amalinagar to Dhanushkodi. Sampling site details, including coordinates and transects, are provided in Table 10.1.

10.5. Methodology

10.5.1. Shoreline litter sampling (Lippiatt et al., 2013)

- ALDFG was recorded based on count, weight, and relative abundance (% of total litter) according to the NOAA Marine Debris Program.

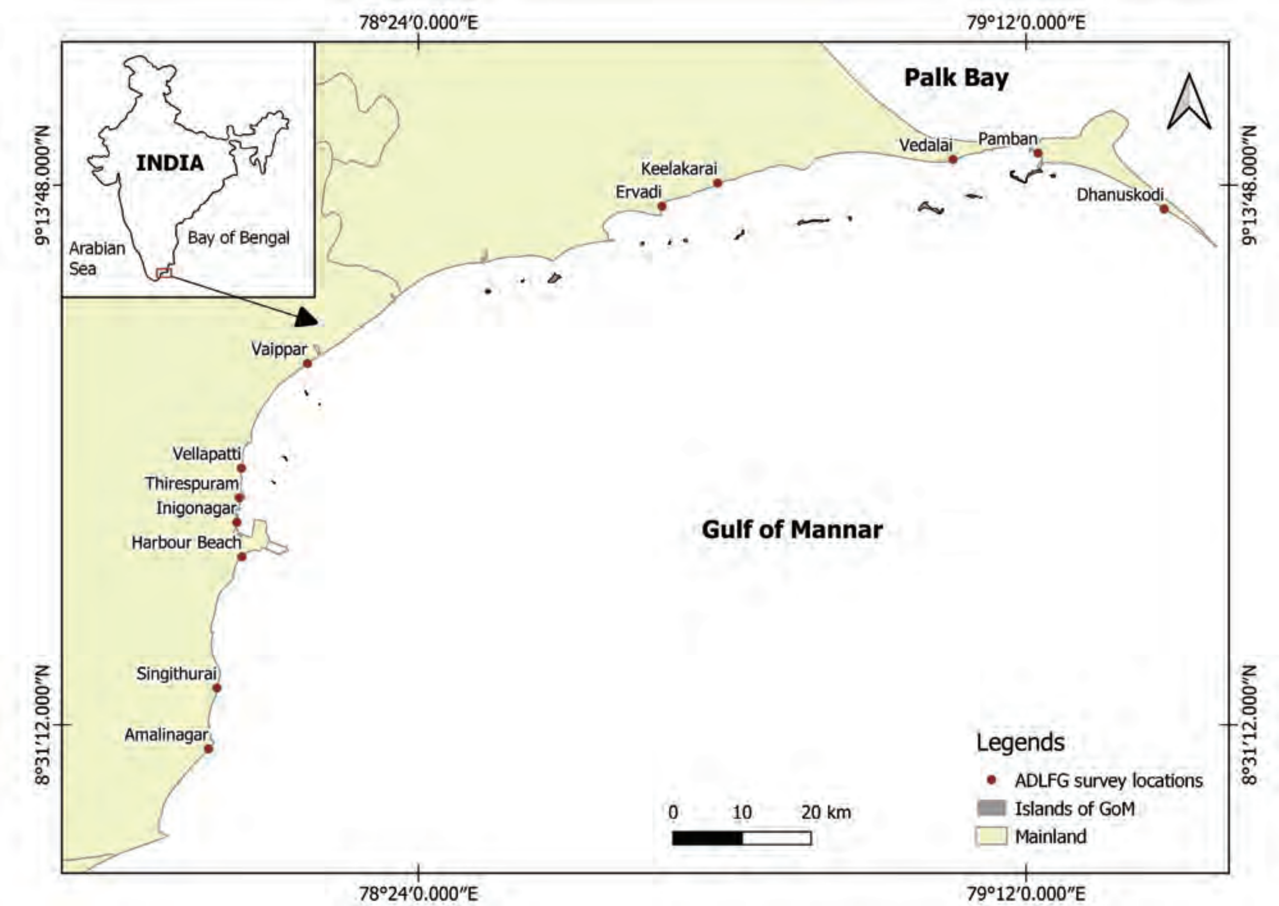


Fig.10.1: Map showing the sampling sites for the assessment of ALDFG (macro and microplastics) in 12 locations along the coast of GoM

Table 10.1. Details of ALDFG sampling locations

S No	Survey Locations	District	Coastal Length (Meter)	Transects	Coordinates
1	Dhanuskodi	Ramanathapuram	400	4	Lat. 9°11'55.25"N Long. 79°22'55.01"E
2	Pamban	Ramanathapuram	450	8	Lat. 9°16'19.78"N Long. 79°12'56.98"E
3	Vedhalai	Ramanathapuram	550	8	Lat. 9°15'49.87"N Long. 79° 6'13.94"E
4	Keelakarai	Ramanathapuram	700	4	Lat. 9°13'34.30"N Long. 78°46'58.30"E
5	Ervadi	Ramanathapuram	400	8	Lat. 9°12'8.24"N Long. 78°43'14.10"E
6	Vaippar	Tuticorin	600	4	Lat. 8°59'43.28"N Long. 78°15'14.03"E
7	Vellapatti	Tuticorin	400	4	Lat. 8°51'27.14"N Long. 78°10'0.60"E
8	Thirespuram	Tuticorin	800	4	Lat. 8°48'46.84"N Long. 78° 9'49.28"E
9	Inigonagar	Tuticorin	500	4	Lat. 8°47'20.43"N Long. 78° 9'41.72"E
10	Harbour Beach	Tuticorin	600	4	Lat. 8°44'35.23"N Long. 78°10'11.88"E
11	Singithurai	Tuticorin	700	4	Lat. 8°34'5.94"N Long. 78° 8'4.24"E
12	Amalinagar	Tuticorin	500	4	Lat. 8°29'17.19"N Long. 78° 7'24.81"E

10.5.2. Sample collection

- Four 5 m-wide transects were fixed randomly along 100 m shoreline sections.
- All anthropogenic debris (>2.5 cm) within each transect was collected, sorted, counted, and weighed.

10.5.3. Data quantification

- ALDFG was quantified as items/m^2 and kg/m^2.
- ALDFG concentration was calculated using:
- C=n/w×l, where **C** = debris concentration, **n** = ALDFG items, **w** = transect width (5m), and **l** = shoreline length.
- Polymer composition was analyzed using FTIR-ATR (Thermo Nicolet iS5).

10.6. Shoreline survey results

10.6.1. Abundance of ALDFG in the Gulf of Mannar

The GoM shoreline is a significant zone for studying ALDFG, which comprises 50% of the total marine litter in this region. This stark division between ALDFG and other debris highlights the serious impact of fisheries-related activities on marine pollution.

Among the components of ALDFG, ropes represented the most prominent category, accounting for 38% of the total ALDFG. Fishing nets contributed 6%, along with fishing traps(6%) and lines(0.3%), indicating the varied sources of discarded gear (Fig.10.2).

The remaining 50% included other non-fishery debris, underlining the mixed nature of marine litter in this biodiversity hotspot. ALDFG items constituted a dominant part of microplastics found on beaches. Larger plastic items and fragments in the natural environment were major contributors to the accumulation of microplastics.

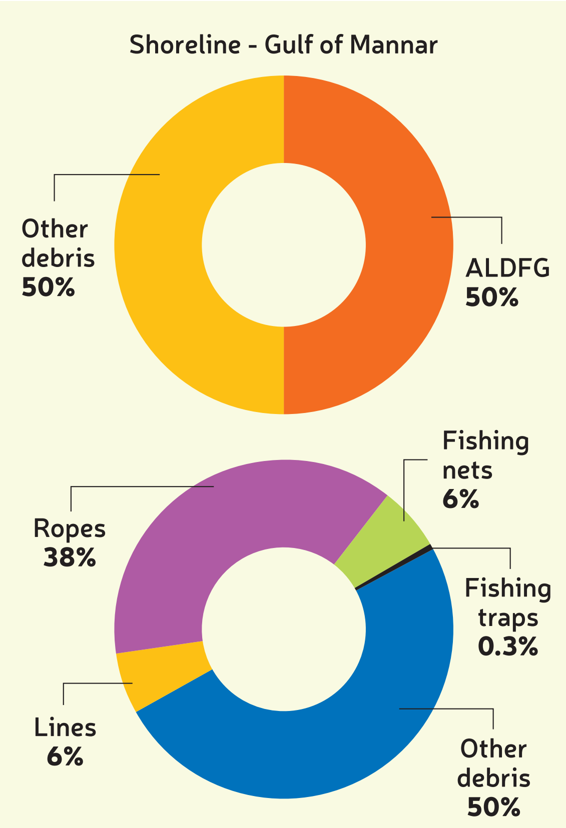


Fig.10.2: Abundance of ALDFG in the Gulf of Mannar

The prevalence of ALDFG in the GoM not only threatens marine ecosystems but also underscores the necessity for enhanced waste management systems, gear recovery initiatives, and awareness campaigns targeting sustainable fishing practices.

10.6.2. Seasonal variation in ALDFG concentration and weight

Seasonal variations in ALDFG composition were more pronounced during summer, with evident spatial differences. The highest concentration of ALDFG was recorded at Thirespuram, while the lowest was observed at Harbour Beach in Tuticorin district. In terms of weight, Thirespuram exhibited the largest accumulation of ALDFG.

During the summer season, the average number of fishing-related ALDFG items was 58.1 ± 12.35/m^2, whereas during the monsoon season, it was significantly lower at 32.4 ± 10.24/m^2. Beaches with higher fishing intensity recorded the greatest ALDFG densities, reaching 258.8 items/m^2 in summer and 85.9 items/m^2 in monsoon, while beaches with lower fishing intensity had considerably fewer items (6.1 items/m^2 in summer and3.5 items/m^2 in monsoon) (Fig.10.3a).

The significant increase in ALDFG abundance during summer can be attributed to the effects of intense sunlight, which weakens plastic debris, making it brittle and more prone to fragmentation (Crawford and Quinn, 2017). Conversely, monsoonal rainfall can result in the displacement of plastic waste, either washing debris away or leading to leachate formation, transporting pollutants into coastal waters.

Weight-based estimations (Fig.10.3b) also revealed seasonal and fishing intensity-related variations. The greater share of ALDFG by weight during the monsoon can be attributed to the presence of larger-sized discarded fishing gear accumulating on the beaches. The higher debris density observed during summer may be influenced by increased wave activity, which enhances the formation of extensive wrack lines, trapping more debris along the shoreline (Jayasiri et al., 2013).

The predominant components of ALDFG were ropes, gillnets, floats, buoys, longlines, and fishing lines. Seasonal variations in the composition revealed minor differences, with ropes consistently dominating the ALDFG across both seasons. During the monsoon season (Fig.10.4a), ropes accounted for 58.52% of the debris by number (No./m^2) and 48.28% by weight (kg/m^2). Next in order were gillnets and floats, contributing 12.27% and 16.99% by number, and 27.76% and 2.66% by weight respectively. Other items, such as longlines (10.86% by number and 3.41% by weight), traps, and fishing lures, were present in smaller proportions.

The ALDFG composition during the summer season was dominated by rope (48.28%), indicating its widespread use and frequent loss in fishing activities. Gillnets and similar nets

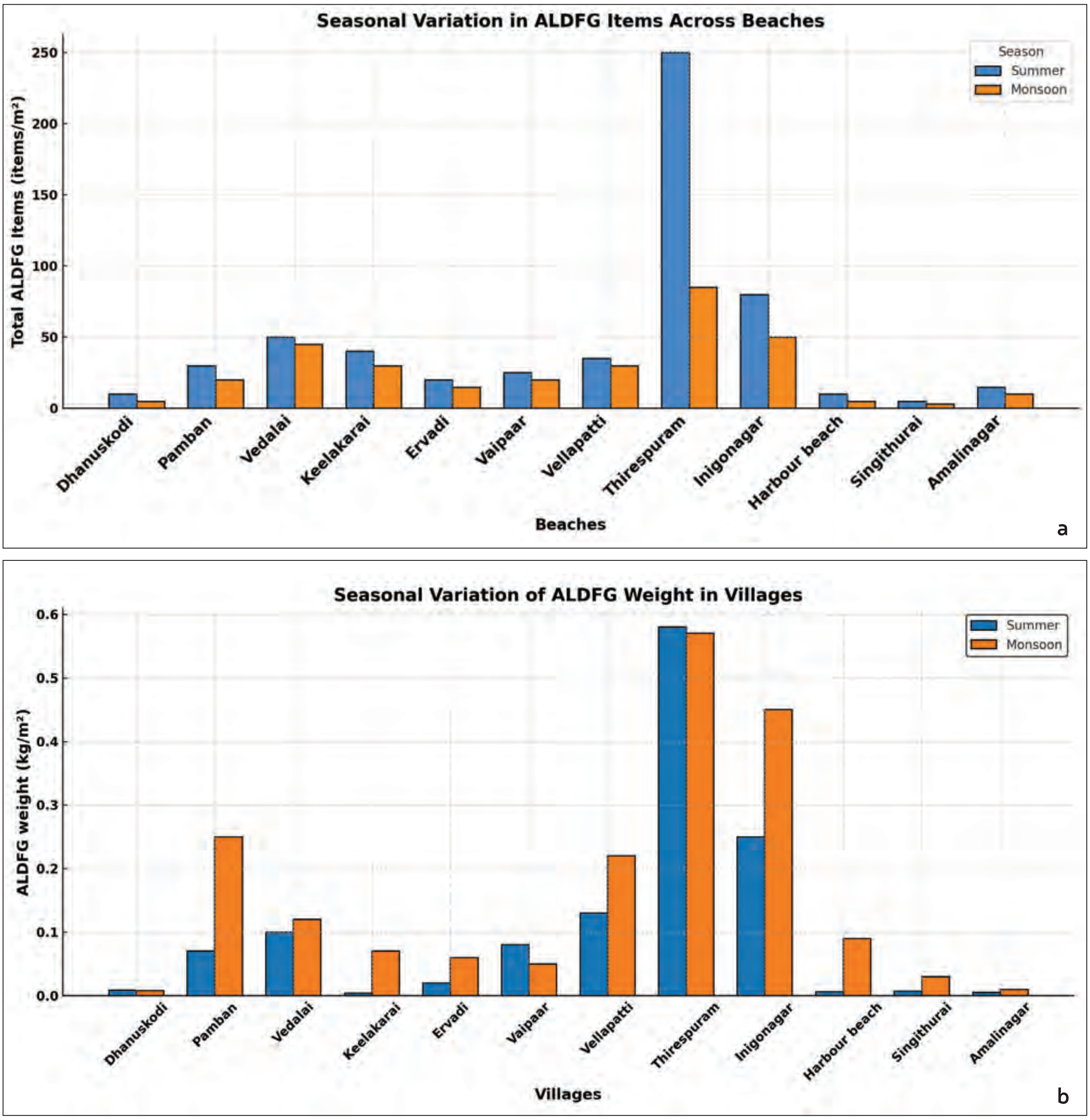


Fig.10.3: Variation in abundance of ALDFG fishing-related debris by number **(a)** and by weight **(b)** across 12 surveyed beaches during summer and monsoon

(27.76%) were the second most common items, likely due to entanglement, breakage, or loss during operations. Traps (16.53%) also contributed significantly, possibly due to damage or misplacement in the marine environment. Other gear types, such as longlines & hooks (3.41%), floats & buoys (2.60%), seines (1.27%), fishing lures & line (0.08%), and trawl nets (0.01%)contributed in smaller proportions, suggesting lower loss rates or better management (Fig.10.4b). The dominance of ropes and nets highlighted the challenges in gear management and retrieval, while the

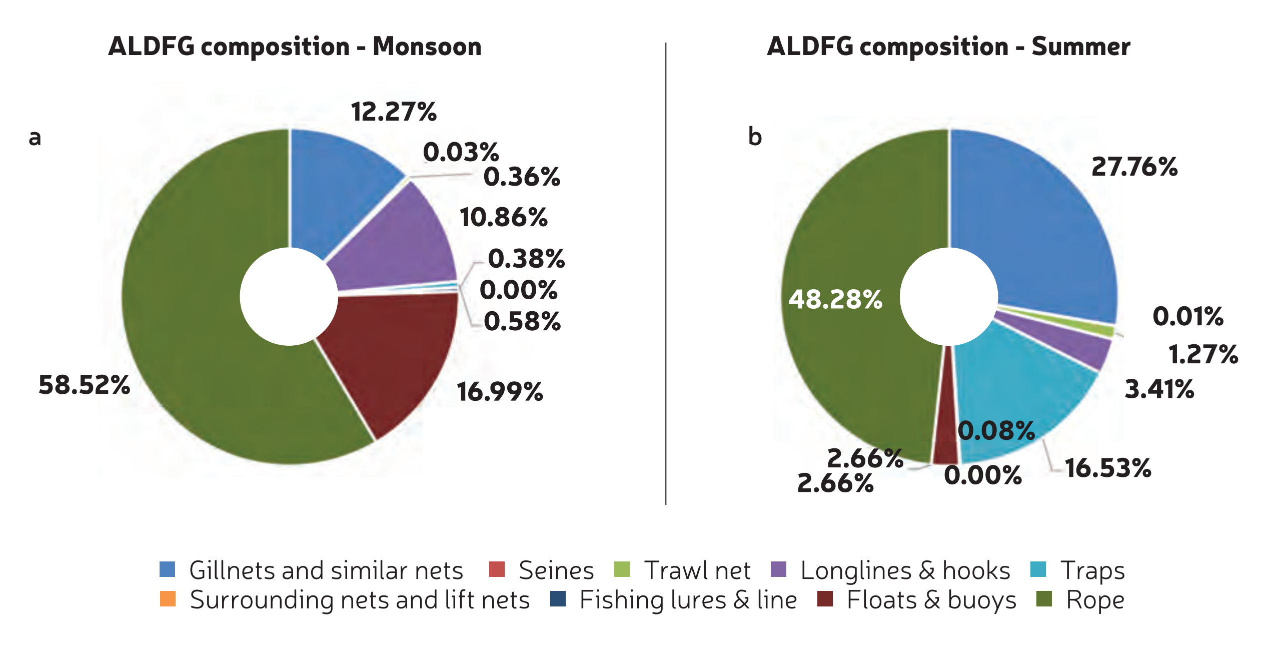


Fig. 10.4: Percentage composition ALDFG collected during monsoon **(a)** and summer **(b)** along beaches of GoM Coast

presence of traps and floats suggested losses due to rough sea conditions or inadequate retrieval mechanisms.

The seasonal accumulation of ALDFG is influenced by factors such as monsoonal currents, beach topography, and tidal actions. Heavier items like ropes tend to remain concentrated, while lighter and smaller debris is often dispersed or buried. These results align with global trends, where fishing-related debris, including nets, ropes, and buoys, constitutes a significant portion of marine litter. Understanding these patterns is essential for developing targeted management strategies to mitigate the impact of ALDFG on coastal and marine ecosystems.

10.6.4. Polymer composition

The fishing gear consisted of various synthetic polymers, including polyamide (nylon), polyethylene, and polypropylene, contributing significantly to plastic waste (Fig.10.5). The polymers of the solid waste deposited near the beaches could be transported via ocean currents or tides and may accumulate with sedimentation.

10.6.5. Solid waste dumping areas

Among the 12 study sites, notable solid waste sites near the shore were observed in only two locations (Pamban and Vedalai) in Ramanathapuram District. The area coverage of the solid waste dump site was 192m^2 in Pamban, while Vedalai had an area of 321m^2 in site 1, 180 m^2 in site 2, and 111 m^2 in site 3. About 65% of this litter was mainly plastics, aluminium, and glass. The remaining 35% of litter was fishery by-catches (Table 10.2).

10.7. Fisherfolk's perspectives on marine litter and fisheries waste

Fisherfolk highlighted critical concerns regarding marine litter and fisheries waste. Bottom-set gillnets, followed by standard gillnets, were identified as having the most detrimental impacts on the marine environment. Fisherfolk also noted that gillnets are the most frequently lost gear during fishing activities. One of the significant challenges raised was the lack of designated locations to dispose of used fishing gear. Despite this, fishers from both nations expressed willingness to support systems designed to collect and manage old fishing gear effectively.

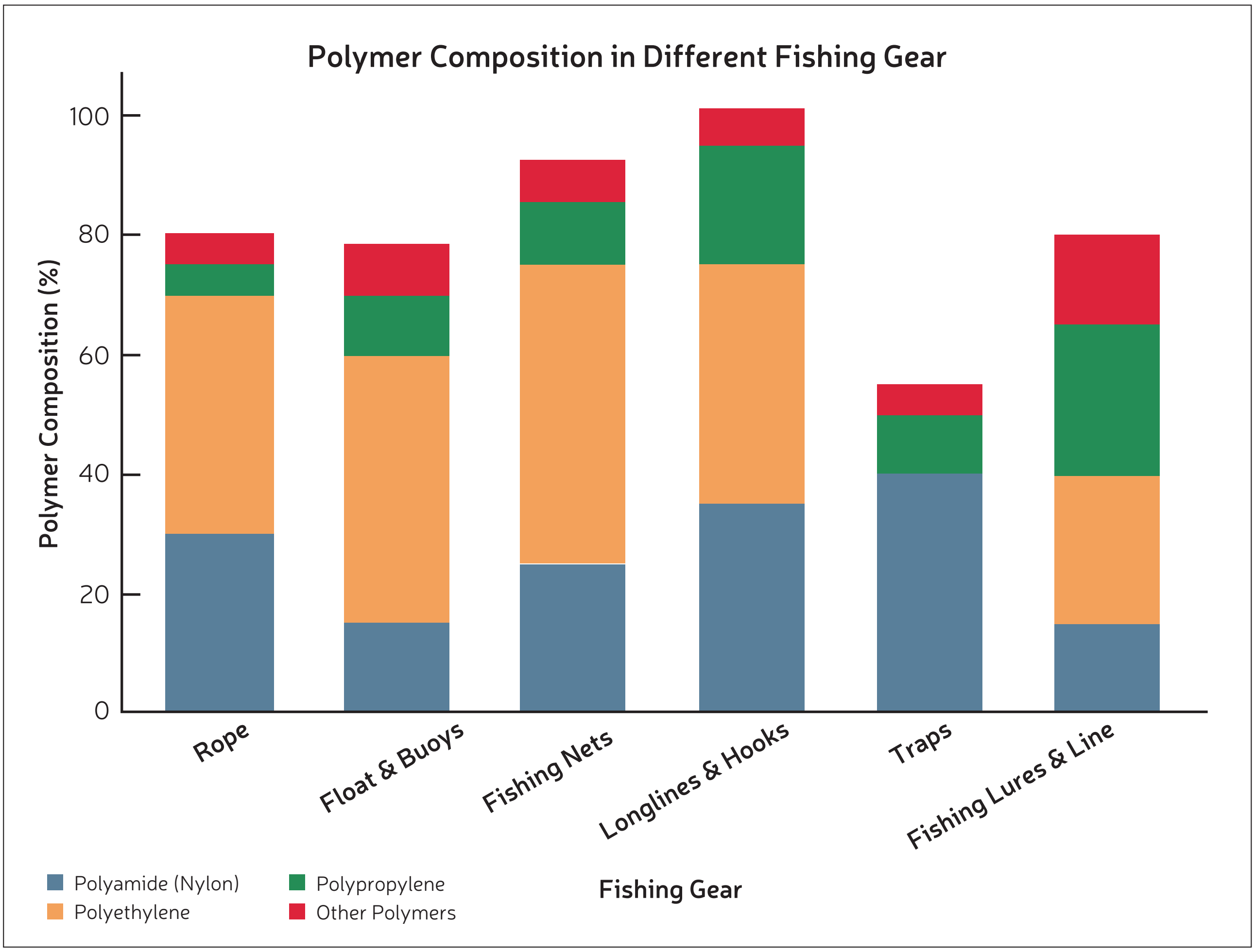


Fig.10.5: Polymer composition of the different fishing gear collected from GoM

10.8. Identified issues and recommendations related to ALDFG in the Gulf of Mannar

10.8.1. Key issues

1. **Lack of awareness & knowledge** – Fishers has limited understanding of ALDFG impacts and mitigation measures.
2. **Lack of alternative livelihoods** – Fishers lack supplementary income sources, with increasing dependency on fishing.
3. **Absence of incentives for recycling** – No policies exist for fishing gear recycling, recovery, or reuse.
4. **Gear conflicts & Data gaps** – Lack of accurate statistics on gear losses and insufficient reporting mechanisms.
5. **Ineffective cleanup mechanisms** – No structured programs for retrieving lost fishing gear.
6. **Bottom snagging & Ghost fishing** – Lost gear continues to trap marine life, affecting biodiversity.
7. **Illegal Fishing in Marine Protected Areas (MPAs)** – Weak enforcement of existing bans leads to gear loss in sensitive habitats.
8. **Unsustainable gear design** – Most fishing gear lacks biodegradable components, intensifying ghost fishing.
9. **Knowledge gaps** – Limited research on ALDFG density, environmental impact, and recycling potential.
10. **Weak policy & enforcement** – No unified monitoring body to address ALDFG issues systematically.


Koli

Table 10.2. Assessment of solid waste dumping areas for marine debris and ALDFG at 12 study sites in GoM

Sampling Sites	No. of Dumping Sites	Solid Waste Dumping Area (m^2)	Waste Composition
Pamban	1	192	Domestic waste (100%) (plastic bottles, covers, clothes)
Vedalai	Site (1)	321	Fishing nets (25%), buoys (25%), ropes (20%), and domestic waste (30%)
	Site (2)	180	Fishing nets (50%), buoys (25%), and domestic waste (25%)
	Site (3)	111	Fishing ropes (30%), nets (25%), traps (10%), buoys (15%), and domestic waste (20%)
Other	-	-	No dumping sites found in Dhanuskodi, Keelakarai, Ervadi, Vaippar, Vellapatti, Thirespuram, Inigonagar, Harbour beach, Singithurai, and Amalinagar

10.8.2. Recommended measures

1. **Education & awareness** - Install information posters at fish landing sites, engage fishers in citizen science initiatives, and implement digital training programs.
2. **Livelihood support** - Establish Public-Private-People Partnerships to introduce alternative livelihood training and financial security programs.
3. **Recycling & Waste management** - Implement extended producer responsibility, take-back schemes, and develop recyclable fishing gear.
4. **Policy & regulation** - Mandate reporting of fishing gear loss, enforce bans on net use in reef habitats, and introduce spatial management systems for marine protected areas.
5. **Cleanup programs** - Adopt the "Fishing for Litter" approach, conduct reef cleanups, and incentivize retrieval of lost gear.
6. **Gear innovation** - Introduce biodegradable components, promote gear certification, and regulate alternative materials for fishing gear.
7. **Research & Technology development** - Conduct studies on ALDFG distribution, financial value chains, and environmental costs. Implement mapping tools for lost gear identification.
8. **Strengthened governance** - Establish a centralized monitoring body for ALDFG enforcement and introduce a dashboard system for real-time tracking.

11

EDUCATING AND EMPOWERING FISHERFOLK IN COMBATING MARINE LITTER AND PROTECTING BIODIVERSITY

11. EDUCATING AND EMPOWERING FISHERFOLK IN COMBATING MARINE LITTER AND PROTECTING BIODIVERSITY

11.1. Back ground

Marine debris, especially plastics and ALDFG, threatens marine ecosystems and fisheries. Fisherfolk play a vital role in addressing this issue. This chapter highlights the importance of awareness creation programs aimed at educating fisherfolk on marine litter reduction and biodiversity conservation. The Tamil Nadu Pollution Control Board (TNPCB) has conducted programs to educate stakeholders, including fisherfolk, on the impacts of ALDFG and plastic waste.

In Kasimedu Fishing Harbour, Chennai, awareness creation programs focused on the collection and segregation of discarded and ghost fishing nets were conducted. These programs emphasized sustainable waste management and community-driven solutions. Encouraged by their success, similar efforts are being taken in other fishing villages along Tamil Nadu coast to promote responsible fishing and marine conservation.

11.2. Importance of awareness programs

- **Understanding marine debris:** Raising awareness about marine debris and its impacts on ecosystems, fisheries, and human livelihoods.

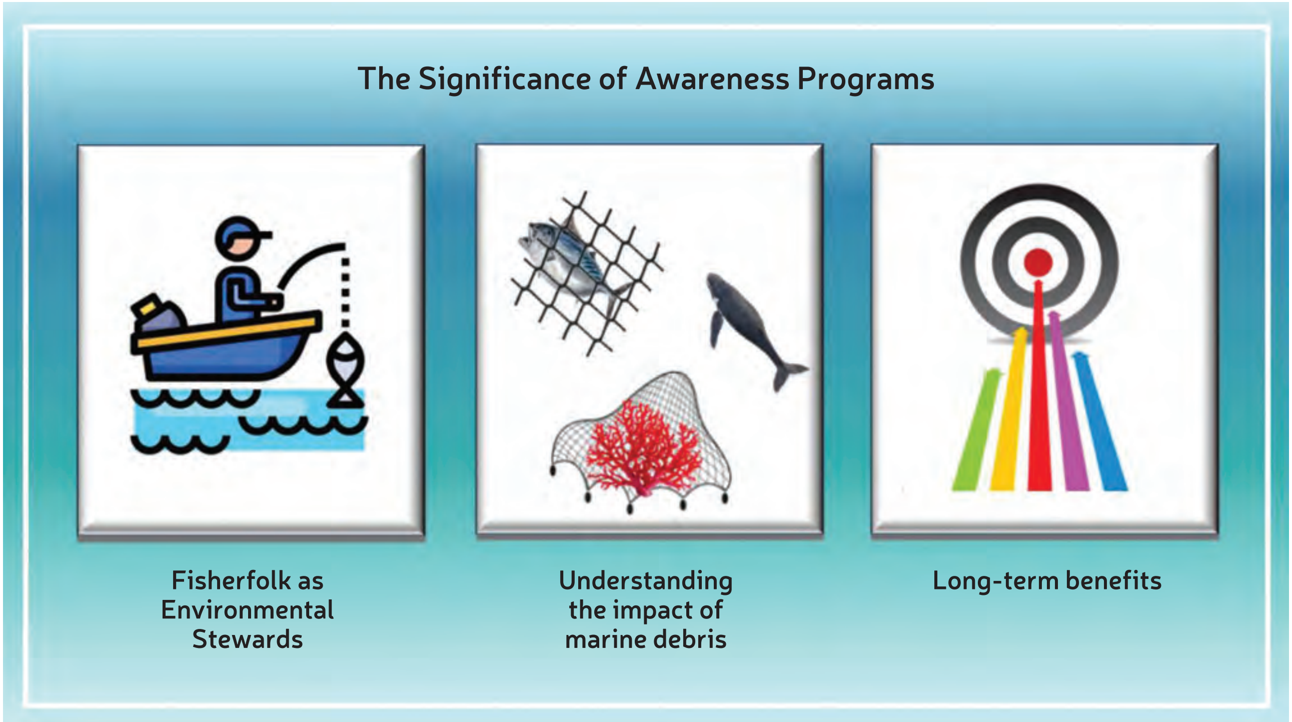


Fig. 11.1: Impact of awareness programs on sustainable fishnet waste management

- **Fisherfolk as environmental stewards:** Encouraging the adoption of sustainable fishing practices and responsible waste disposal.

- **Long-term benefits:** Protecting fish stocks, maintaining clean beaches, and improving the well-being of coastal communities (Fig.11.1).

11.3. Key awareness initiatives for sustainable fishnet waste management

Targeted awareness programs were conducted to engage key stakeholders in responsible fishnet disposal and recycling, promoting community-driven solutions for ALDFG (Fig.11.2).

- **Boat owners' associations** - Educated on responsible gear disposal and participation in collection programs.

- **Fishnet collection shop operators** - Trained to properly utilize the shops as collection centers for used nets, promoting recycling.

- **Fishermen's welfare associations** - Engaged to spread awareness about ALDFG's environmental impact and sustainable alternatives.

- **Local trash collectors** - Trained in proper segregation and handling of discarded fishnets.

- **Fishermen's children** - Involved in educational programs to instil long-term environmental responsibility.

11.3.1. Awareness to the fisherfolk for the collection and segregation of discarded and ghost fishing nets

ALDFG poses a severe threat to marine ecosystems by entangling marine life and contributing to persistent pollution. Awareness programs have been conducted to educate fisherfolk on the environmental consequences of ALDFG and to promote best practices for collection, segregation, and disposal (Fig.11.3). Training sessions emphasized the importance of timely reporting and retrieval of lost nets. The trainees were encouraged to recover lost nets / to remove torn nets strewn in intertidal zones and beaches during

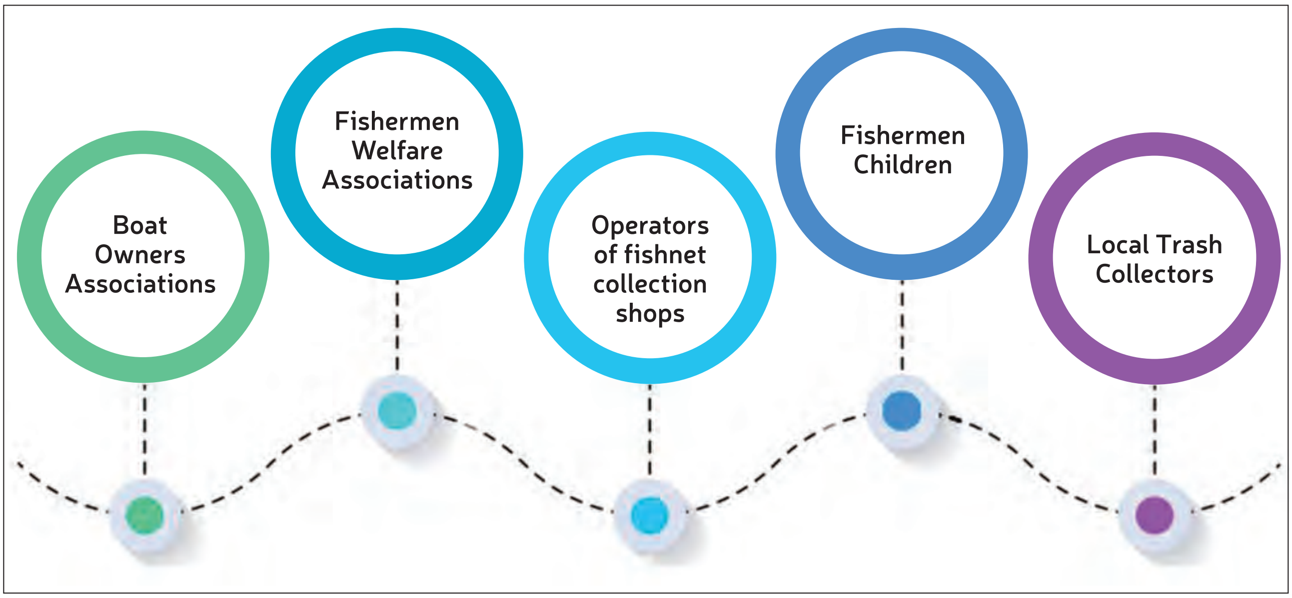


Fig. 11.2: Key stakeholders in fishnet waste management awareness programs

their fishing activities. Practical demonstrations were held to showcase effective waste management techniques and promote sustainable fishing practices. Financial incentives were introduced to motivate fisherfolk to actively participate in these initiatives. Collection centers were established to streamline the disposal process, ensuring that retrieved nets were efficiently processed. At these centers, nets were segregated based on materials such as polyamide (PA), polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) to facilitate recycling. Fisherfolk were trained on how proper segregation enhances the value of discarded nets and prevents environmental damage.

A notable impact was observed in Kasimedu, Chennai, where around 60 kg of fishnet waste is generated daily. Previously, torn nets were discarded into the ocean, dumped in dustbins, or sold to scrap dealers without clear recycling pathways. The awareness initiative successfully transformed these practices, with fisherfolk now actively engaging in responsible fishnet disposal. They learnt how discarded nets could be repurposed into ropes, carpets, and other valuable products, strengthening the circular economy. Interactive sessions with fishermen, boat owners, and fishing associations facilitated discussions on establishing fishnet collection facilities, ensuring a long-term waste management solution. Many participants expressed interest in setting up dedicated collection points, reinforcing community-led efforts to combat marine litter. These awareness efforts have fostered environmental consciousness among coastal communities, empowering them to actively reduce marine pollution.

11.3.2. Engagement with boat owners' associations

The awareness programs at Kasimedu Fishing Harbour engaged boat owners' associations, recognizing their key role in promoting responsible fishing practices and waste management. Discussions highlighted the impact of discarded fishing gear on marine ecosystems and the fishing industry, including reduced fish stocks and increased vessel maintenance costs. Boat owners were encouraged to collaborate with local authorities and environmental agencies to implement sustainable waste management practices, such as designated storage for damaged nets and proper disposal at collection centers. They were also urged to promote awareness among crew members, reinforcing responsible waste disposal

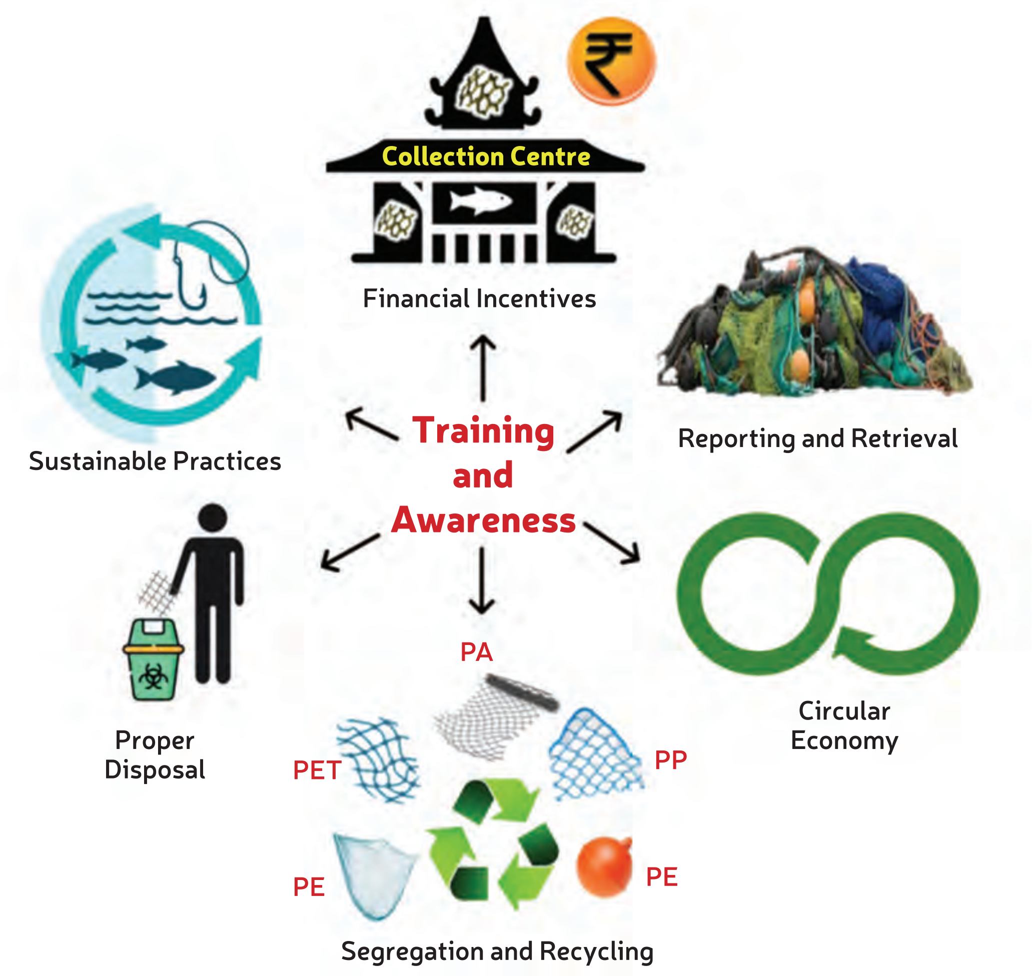


Fig. 11.3: Empowering fisherfolk in the collection and segregation of discarded and ghost fishing nets

practices. Their involvement has contributed to fostering long-term behavioural change for a cleaner marine environment.

11.3.3. Awareness to the fishermen's welfare associations

Fishermen's welfare associations play a crucial role in promoting sustainable fishing practices and community well-being. Awareness programs were conducted to strengthen their role in addressing the issue of marine debris, particularly discarded and ghost fishing nets. These initiatives emphasized the long-term impacts of ALDFG on fisheries, marine habitats, and coastal livelihoods. Associations were encouraged to integrate marine conservation awareness into their regular activities. Incentive-based programs were introduced, offering financial benefits, discounts on new gear, or alternative livelihood opportunities for responsible waste disposal. Collaborations with local authorities helped establish reward systems for fishermen retrieving and properly disposing of damaged nets. Training sessions equipped welfare association leaders with tools to advocate for sustainable waste management policies. By actively involving fishermen and fostering shared responsibility, these programs have encouraged long-term behavioural change to ensure the cleanliness of the marine environment.

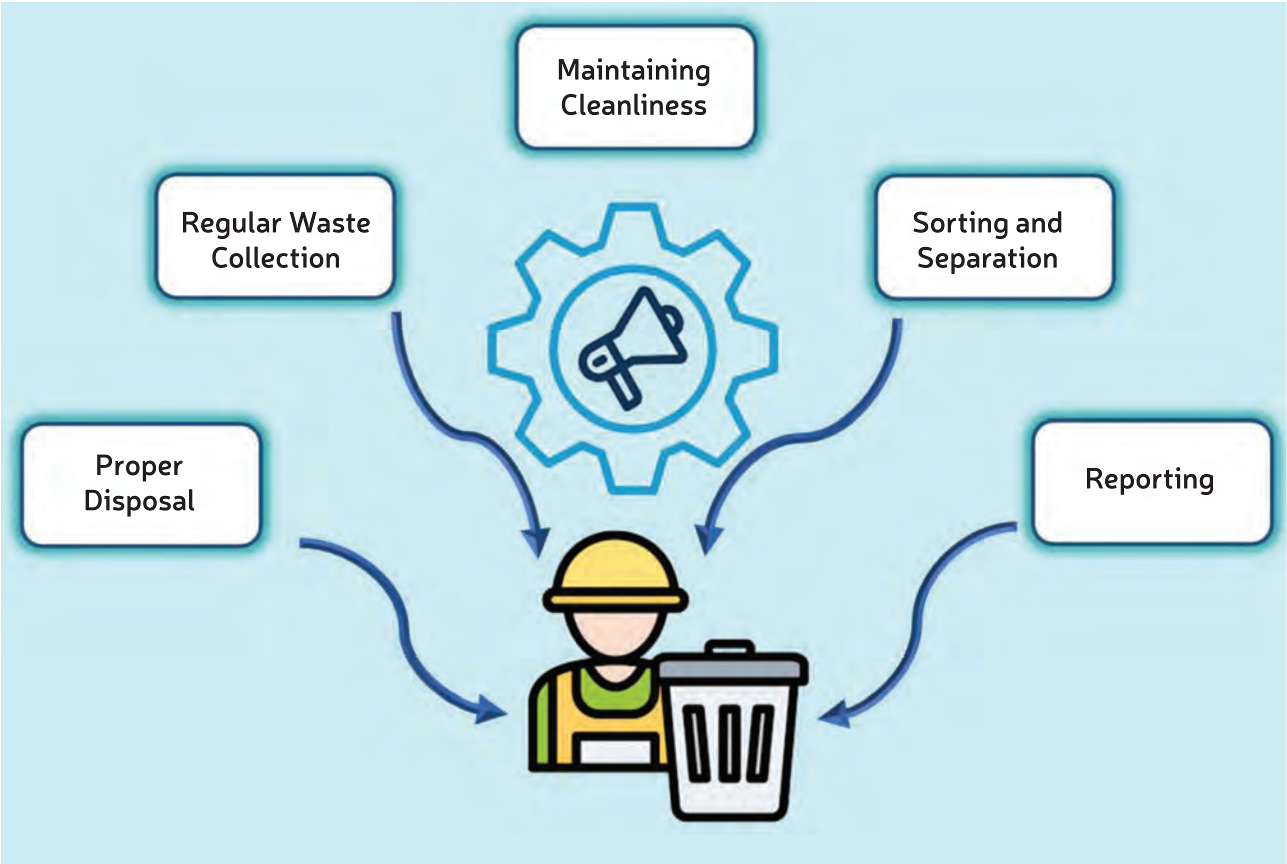


Fig. 11.4: Guidelines for local trash collectors

11.3.4. Awareness to the local trash collectors

Trash collectors play a vital role in maintaining coastal cleanliness and supporting environmental sustainability. Awareness programs were conducted to educate them on the importance of proper collection, segregation, and disposal of discarded fishing nets and plastic debris. Specific instructions were provided on safe handling and transportation of abandoned nets to designated recycling facilities, thereby preventing their accumulation in landfills or oceans (Fig. 11.4). They were also encouraged to report any ghost nets or discarded fishing gear encountered during their work to local authorities or environmental organizations for timely removal. Such awareness ensures that waste management personnel contribute effectively to reducing the impacts of ghost gear and marine litter.

This initiative streamlined waste management efforts and promoted systematic handling of fishing-related debris. Partnerships with local authorities and non-governmental organizations (NGOs) further supported the program by providing safety gear and improving working conditions for trash collectors, acknowledging their essential role in maintaining coastal cleanliness. In addition, community engagement activities were organized to bridge the gap between fisherfolk and trash collectors, fostering collaboration in tackling marine litter. Trash collectors were also encouraged to report areas with high concentrations of discarded nets and fishing waste, which enabled more targeted and effective cleanup operations. Overall, these awareness initiatives have empowered trash collectors with both knowledge and resources, strengthening their contribution to marine conservation and sustainable waste reduction.

11.3.5. Awareness imparted by fisheries department to the fishermen's welfare organizations and other associations

Fishermen welfare associations and fisheries-related organizations play a crucial role in promoting sustainable fishing practices. These groups are dedicated not only to the preservation of marine resources but also to the welfare of the fishing communities they represent. One of the pressing challenges they address is marine debris, particularly abandoned and discarded fishing gear.To tackle these issues, the government has initiated workshops and training programs for fishermen's associations in coastal villages. These educational sessions aim to raise awareness about the impacts of marine debris and provide practical solutions. Visual aids such as posters, videos, and interactive presentations are used to make the information more accessible, relatable, and engaging to the fishermen.

Collaboration with local leaders, heads of fishermen's associations, and community influencers is an integral part of this effort. Their active participation amplifies the message, fosters community ownership, and encourages broader participation in addressing environmental challenges. To ensure meaningful progress, the government has also created avenues for fishermen to express concerns, share suggestions, and provide feedback. This inclusive approach values their unique experiences and insights, ensuring they are incorporated into future initiatives. Such collaborative and participatory measures pave the way for more effective and sustainable fishing practices in the region.

11.3.6. Awareness program for fishermen's children in schools

Teaching children about waste management from a young age helps them develop a sense of responsibility for the environment. Early childhood experiences play a pivotal role in shaping long-term attitudes and behaviours, underscoring the necessity of embedding positive environmental values during formative years. Recognizing the importance of early education in fostering environmental stewardship, awareness programs were conducted in schools attended by the children of fishermen. These initiatives aimed to instil a sense of responsibility for marine conservation from a young age, ensuring that future generations understand the impact of marine debris, particularly ALDFG. Interactive sessions, storytelling, and visual presentations were used

Fig. 11.5: Educating future generations on waste impact and responsibility

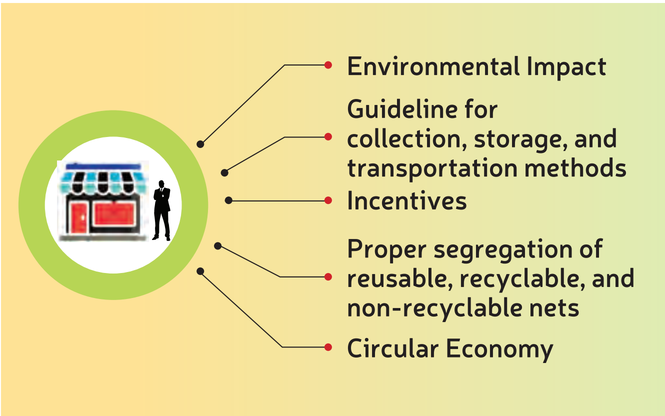


Fig. 11.6: Empowering fishnet collection shops for sustainable marine waste management

to educate students about the dangers of ghost nets, plastic pollution, and their effects on marine life and fisheries. Specially designed educational materials, including posters, activity books, and short films in local languages, helped make learning engaging and relatable. Workshops and beach clean-up drives were organized to provide hands-on experience, encouraging children to actively participate in environmental protection efforts. When children learn about waste management, they can share their knowledge and experiences with their families and friends, creating a ripple effect that promotes broader awareness and positive change. Collaborations with schools, local environmental organizations, and fisheries authorities ensured that marine conservation topics were integrated into school curricula and extracurricular activities (Fig.11.5). The program not only educated young minds but also helped bridge the gap between traditional fishing communities and modern sustainable practices, promoting a long-term cultural shift toward responsible marine resource management.

11.3.7. Awareness among operators of local fishnet collection shops

Local fishnet collection shops play a vital role in managing discarded and end-of-life fishing gear. Awareness programs were conducted to educate shop operators on the environmental impact of abandoned fishing nets and their potential for recycling. Experts trained shop owners and workers on sustainable collection practices, emphasizing the importance of preventing damaged nets from being dumped into the ocean. Operators were encouraged to collaborate with fishermen by offering incentives for depositing worn-out nets instead of discarding them improperly (Fig.11.6).

Torn and bundled-up nets can lead to serious sanitation and health problems, especially during the monsoon season. The unpleasant odour from these nets is hard to bear, and they serve as breeding grounds for mosquitoes. To tackle these issues, guidelines were put in place to standardize the methods for collection, storage, and transportation, which helps to reduce further pollution. Awareness initiatives also facilitated connections between shop operators, recycling units, and local authorities, ensuring that collected nets were processed into useful products such as ropes and carpets. By actively involving collection shop operators in sustainable waste management, the program strengthened the circular economy within the fishing industry, contributing to a cleaner marine environment.

12

ESTABLISHMENT OF DISCARDED FISHNET COLLECTION CENTRE

12. ESTABLISHMENT OF DISCARDED FISHNET COLLECTION CENTRE

12.1. Background

The fishing industry has increasingly relied on plastic-based gear, such as nets, ropes, and traps, due to their durability, affordability, and buoyancy. However, ALDFG has become a major contributor to marine plastic pollution, leading to ghost fishing, habitat destruction, and plastic ingestion by marine life. Fishing gear is often lost due to rough weather, wear-and-tear, or vessel crashes, while in some illegal and unregulated fisheries old / damaged fishing gear are intentionally discarded into the sea. Additionally, low-quality nets discarded after a single season significantly contribute to marine plastic debris (Thomas et al., 2013). Globally, ALDFG accounts for 10% of marine litter by volume (Macfadyen et al., 2009). When they are degraded into microplastics (<5 mm), it is nearly impossible to trace their sources.

In recognition of the urgency of the issue, the TN Fishnet Initiative (TNFI) was announced in the 2023-24 Tamil Nadu budget session; and Honourable Minister for Environment, Forest & Climate Change allocated Rs. 1 crore for the initiative to collect and recycle ALDFG and ghost nets to protect marine biodiversity and support fisher livelihoods. The Tamil Nadu Pollution Control Board (TNPCB) is coordinating efforts with the Fisheries Department, research institutions, NGOs, and fishermen organizations.

Key activities under TNFI include:

- Baseline survey
- Awareness campaigns for fisherfolk and recyclers
- Pilot collection centres for discarded fishnets
- Developing an Extended Producer Responsibility (EPR) program for fishing gear
- Promoting alternative livelihoods

Fig. 12.1: Role of fishnet collection centres in sustainable waste management and marine conservation

This initiative aims to conserve marine biodiversity by actively involving local communities in collecting and managing used fishing nets. The baseline survey was carried out by SDMRI to assess fisheries-related plastic pollution along the Tamil Nadu coast. Following this initiative, the first discarded fishnet collection centre was established at Kasimedu Fishing Harbour as a strategic starting point to mitigate fisheries-driven plastic pollution and promote responsible fishing practices.

This collection centre aims to:

- **Facilitate proper waste disposal** - Providing a designated space for fishermen to deposit damaged and unusable nets instead of discarding them in the ocean or landfills.
- **Promote recycling and circular economy** - Enabling the segregation of recyclable nets, which can be processed into new products such as ropes, fabrics, and plastic components.
- **Reduce marine pollution** - Preventing ghost nets from entangling marine life and damaging habitats.
- **Encourage fishermen's participation** - Incentivizing responsible waste disposal through awareness and potential financial benefits (Fig.12.1).

The initiative at Kasimedu, one of Tamil Nadu's largest fishing hubs, marks a pilot effort toward scaling up discarded fishnet collection centres across other key fishing harbours along the coast.

12.2. Objectives

12.2.1. Baseline study

A comprehensive baseline study was conducted to assess the extent of ALDFG pollution along the Tamil Nadu coast. This study helped in:

- Identifying the discarded fishing gear accumulation
- Analyzing the composition, sources, and impacts of fishnet-related marine litter
- Understanding fishermen's current waste disposal practices and the challenges
- Providing scientific data to support policy interventions and targeted waste management strategies (Fig.12.2)

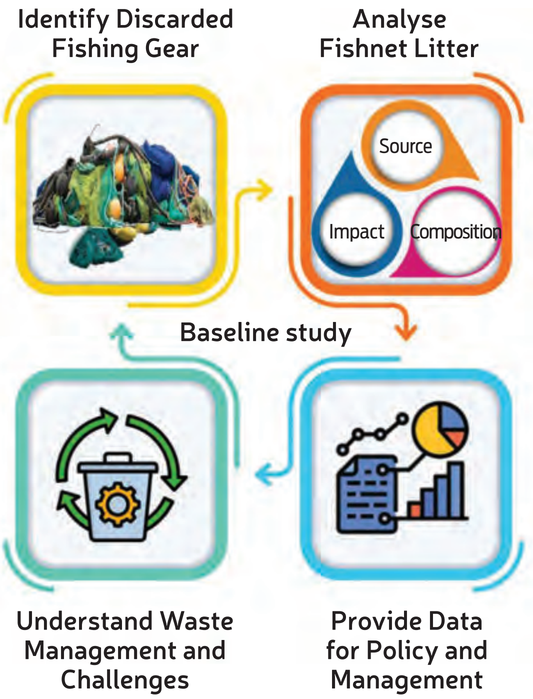


Fig. 12.2: Establishing a baseline for ALDFG management: Identifying, analysing and addressing fishnet litter along Tamil Nadu coast

12.2.2. Establishment of discarded fishnet collection centres

To provide a structured and responsible disposal mechanism, TNFI facilitates the establishment of discarded fishnet collection centres at key fishing harbors.

These centres, acting as designated drop-off points for damaged and end-of-life fishing nets, can:

- Reduce the direct disposal of fishing nets into the ocean
- Support fishermen by offering an accessible and environment friendly waste disposal option
- Serve as collection hubs for further processing, recycling or repurposing of fishnets

12.2.3. Recycling of collected discarded fishnets

To prevent fishnets from becoming marine litter, TNFI promotes recycling initiatives that transform collected fishing gear into useful products. The objectives of this effort include:

- Developing sustainable recycling pathways for polyethylene, PET and nylon-based nets
- Collaborating with recycling industries to convert fishnets into raw materials for rope, textiles, and other plastic products
- Encouraging circular economy models within the fishing community
- Reducing the dependency on virgin plastic production

12.2.4. Extended Producer Responsibility (EPR) for fishnets

A major goal of TNFI is to establish an Extended Producer Responsibility (EPR) framework for fishing gear manufacturers. This includes:

- Engaging fishing net producers in waste management efforts
- Encouraging manufacturers to take responsibility for the life cycle of their products
- Implementing a buy-back system or incentives for returning used fishing nets
- Developing regulatory frameworks that hold producers accountable for sustainable disposal and recycling of fishing gear

12.2.5. Alternative livelihood opportunities for fisherfolk

To support the economic well-being of fishing communities, TNFI integrates initiatives that create alternative livelihood opportunities linked to sustainable waste management. These efforts:

- Provide income generating opportunities for fisherfolk through fishnet collection and recycling programs
- Promote skill development in areas such as eco-friendly product manufacturing using recycled fishing nets
- Support diversification of income sources, reducing dependence on traditional fishing activities
- Enhance community participation in marine conservation efforts by linking sustainable practices with financial incentives

12.3. Baseline research findings

12.3.1. Baseline study on marine plastic litter along the coastline

A baseline survey conducted by the Suganthi Devadason Marine Research Institute (SDMRI) highlights the significant impact of marine plastic litter, particularly ALDFG, along the Tamil Nadu coastline. The study revealed that ALDFG accounted for 47.46% of the total litter, followed by plastics at 39.64% and non-plastic items at 12.9%. Nylon and polyethylene-based fishing nets formed a major portion of the ALDFG. The survey identified Pudukottai district as having the highest concentration of marine litter, with an estimated 2.68 items/m^2 and 0.20 kg/m^2. Using FAO survey data and the Bootstrap method, the study estimated that Tamil Nadu generates approximately 4,554 tons, with a 95% confidence interval ranging from 3,726 to 5,382 tons, of ALDFG annually. Fishermen interviews further emphasized the urgent need for intervention, as many reported disposing of damaged nets by dumping them into the ocean or selling them to unregulated scrap dealers due to lack of proper disposal infrastructure. Given that all coastal areas are significantly impacted by marine litter, urgent mitigation measures are required. Establishing systematic collection centers,

Fig. 12.3: First discarded fishnet collection centre established at Kasimedu Fishing Harbour, Chennai

strengthening recycling networks, and promoting awareness among fishing communities can play a crucial role in addressing this growing environmental challenge.

12.4. Tamil Nadu's first Discarded Fishnet Collection Centre - a milestone in marine conservation

As a strategic step toward mitigating ALDFG pollution along the Tamil Nadu coast, the first 'Discarded Fishnet Collection Centre' was established at Kasimedu Fishing Harbour, Chennai. This initiative was inaugurated on 14th August 2024 by the Hon'ble Chief Minister of Tamil Nadu (Fig. 12.3).This centre marks a significant step towards reducing marine plastic pollution by systematically collecting ALDFG and ghost nets, which pose a severe threat to marine biodiversity. The initiative serves as a model for sustainable waste management in the fishing sector, encouraging responsible disposal practices and fostering a circular economy approach to marine conservation.

The collection centre aims to:

- Provide a dedicated space for fishermen to dispose of end-of-life fishing nets
- Prevent marine litter accumulation and its adverse effects on aquatic life
- Promote recycling of discarded fishing gear into useful materials
- Lay the groundwork for an Extended Producer Responsibility (EPR) program for fishing nets

By implementing eco-friendly disposal practices, the TNFI initiative not only addresses environmental concerns but also supports alternative livelihoods for fisherfolk. This milestone initiative in Kasimedu is a testament to Tamil Nadu's commitment to ocean sustainability and a cleaner, healthier marine ecosystem.

12.5. Operational overview of the fishnet collection and recycling process at Kasimedu

The Kasimedu discarded fishnet collection centre follows a structured process to ensure that ALDFG is collected, sorted, and recycled efficiently. This initiative not only helps protect marine biodiversity but also provides financial incentives to the fishing community for responsible waste disposal.

12.5.1. Key steps in the collection and recycling processes

1. Collection of discarded fishnets

- Fishermen deposit their old and unserviceable fishnets at the collection centre instead of discarding them into the ocean (Fig.12.4).

2. Sorting and storage

- The nets are weighed, categorized, and recorded using a digital system for tracking and accountability.
- The collected fishnets are segregated based on material type and stored properly before being transported for recycling (Fig.12.5).

3. Incentives for fishermen

- To encourage participation, fisherfolk receive Rs. 40 per kilogram for discarded fishnets, without deductions for inert materials or moisture content (Fig.12.6).
- This approach provides fair compensation, creating an additional income stream while promoting environmental responsibility.

4. Recycling and forward linkages

- The initiative establishes connections with recycling industries to ensure the efficient reuse of collected fishing gear.
- M/s. Recity Networks Pvt. Ltd. has been appointed as the official collection partner by TNPCB. They facilitate the collection process and transport the fishnets to M/s. Sun Polymers for recycling.

Fig. 12.4: Fishermen depositing discarded fishnets at the collection centre

Fig. 12.5: Sorting and weighing of discarded fishnets for recycling

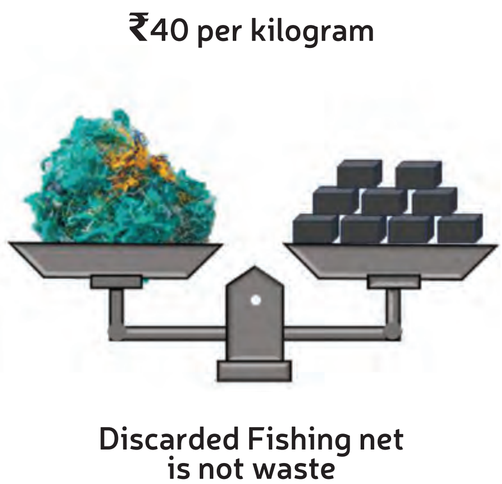


Fig. 12.6: Turning waste into wealth: The economic value of discarded fishing nets

Fig. 12.7: Circular economy approach to discarded fishnets: collection, recycling, and product innovation

This circular economy model ensures that discarded fishing nets do not end up as marine litter but are instead processed into reusable materials. The Kasimedu centre serves as a pilot project, with the potential to expand across Tamil Nadu coastline, paving the way for a sustainable fishing industry and a cleaner marine environment.

12.6. Transforming discarded fishnets: from waste to utility products

ALDFG is a significant contributor to marine plastic pollution along the Tamil Nadu coastline. These synthetic materials persist in the marine environment for decades, posing entanglement hazards to marine fauna and accelerating the degradation of sensitive coastal ecosystems. A promising model to address this issue is illustrated in Fig. 12.7, which outlines a circular economy approach to managing discarded fishing gear through collection, recycling, and product innovation.

To combat the ALDFG issue, the discarded fishnet collection centre was established as a sustainable solution to recover and recycle fishing gear. By systematically collecting, sorting, and processing these materials, the initiative ensures that ALDFG is diverted from marine environments and repurposed into valuable products.

12.6.1. Types of discarded fishnet materials accepted for recycling

The following materials are accepted at the collection center (Fig.12.8):

- Nylon fishnets
- High-Density Polyethylene (HDPE) fishnets
- HDPE & Polyvinyl Chloride (PVC) floaters
- PVC & Polypropylene (PP) ropes
- Polyethylene Terephthalate (PET)
- Other HDPE, PVC, & PP components

12.6.2. Recycling process and end-use products

Once collected, these materials undergo sorting and processing before being converted into pellets. These recycled plastic pellets serve as raw materials for manufacturing a wide range of sustainable products, reducing dependency on virgin plastic production.

The success of this circular economy model highlights the potential for expanding similar initiatives across Tamil Nadu coastal regions, fostering an economically viable and environmentally responsible approach to managing fishing gear waste.

Fig. 12.8: Materials accepted for recycling in the collection centre

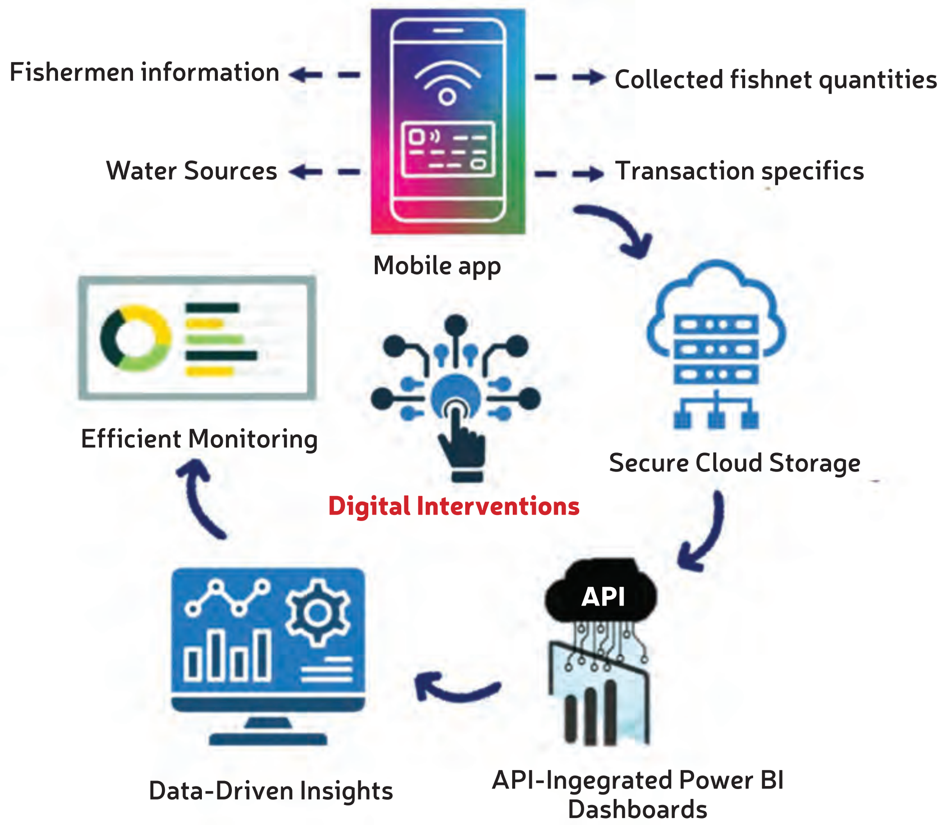


Fig. 12.9: Digital interventions in fishnet collection

12.7. Digital interventions in fishnet collection and monitoring

To enhance transparency, streamline operations, and improve data-driven decision-making, the fishnet collection process has been integrated with digital interventions. These advancements ensure real-time monitoring, accountability, and efficiency in handling discarded fishnets (Fig. 12.9).

12.7.1. Implementation of digital tools

A mobile application is used by authorized field staff to capture critical details such as:

- Fishermen information (who contributed discarded fishnets)
- Collected fishnet quantities
- Waste sources and transaction details

The collected data is securely stored in the cloud, ensuring protection against loss and unauthorized access. The system is API-integrated with Power BI dashboards, allowing real-time monitoring and analysis.

12.7.2. Benefits of digital integration

1. Transparency & accountability: Ensures reliable tracking of collected fishnets.
2. Real time monitoring: Allows instant access to data, improving operational efficiency.
3. Efficient resource allocation: It involves strategically distributing resources (time, budget, personnel, etc.) to maximize productivity, minimize waste, and achieve organizational goals effectively. This information allows for better planning and resource allocation, ensuring that collection resources are available when and where they are needed.

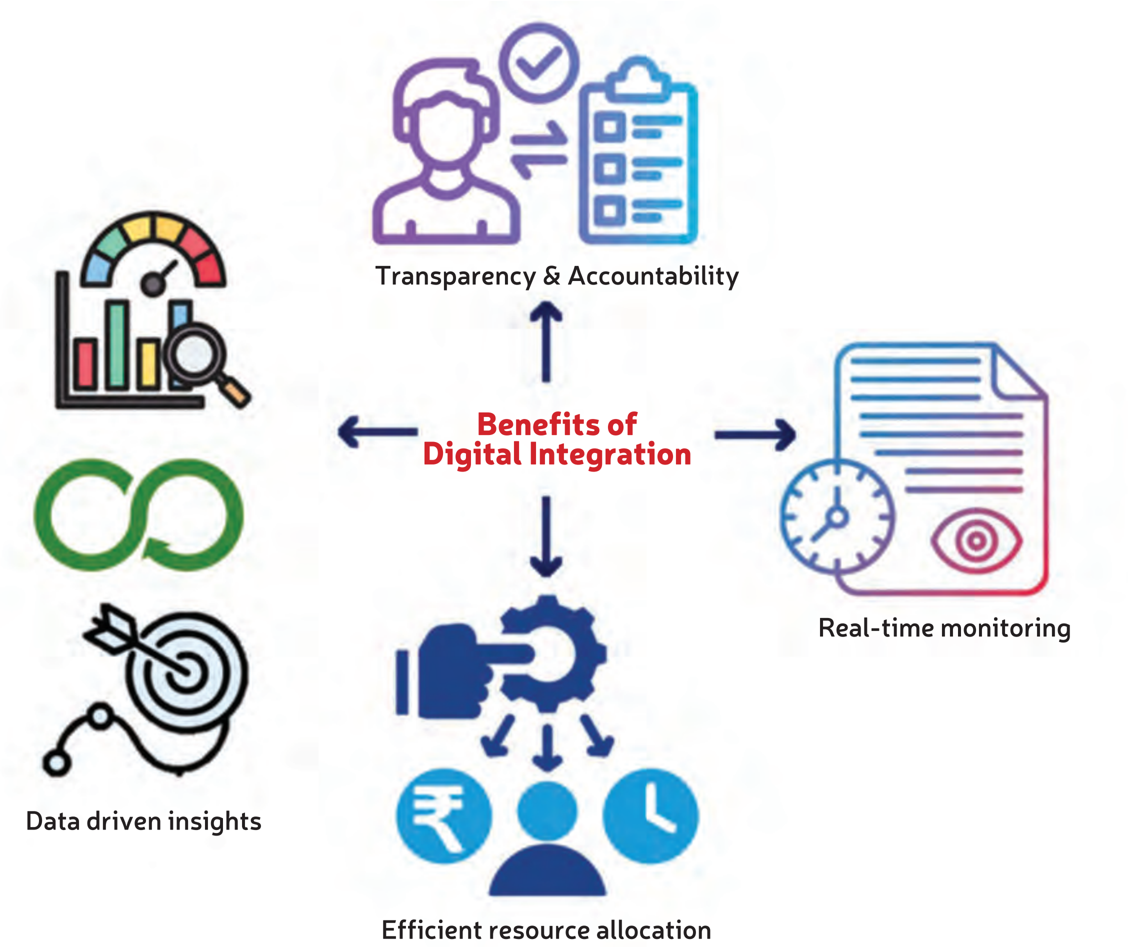


Fig. 12.10: Enhancing efficiency through digital integration

4. Data-driven insights: These are crucial for understanding waste generation and forecasting future volumes. Analyzing waste composition helps to identify targeted interventions to enhance recycling and reduce waste. Data analytics track material flows, promoting a circular economy and minimizing waste. Consistent data collection allows cities to benchmark against others, revealing best practices. This enables effective tracking of key performance indicators (KPIs) like waste diversion rates and recycling effectiveness, supporting operational efficiency and informed policy-making (Fig.12.10).

This technological advancement connects fishermen, collection centers, and recycling units, fostering a sustainable and accountable waste management system.

12.8. Tamil Nadu fishnet initiatives: transforming marine litter into opportunity

The TNFI aims to tackle marine plastic pollution by systematically collecting, processing, and recycling discarded fishing nets. This initiative not only prevents marine litter but also incentivises fishermen to participate in sustainable waste management.

12.8.1. Key achievements

- Quantity of total marine litter collected: 11,189 kg of discarded fishing nets and related waste

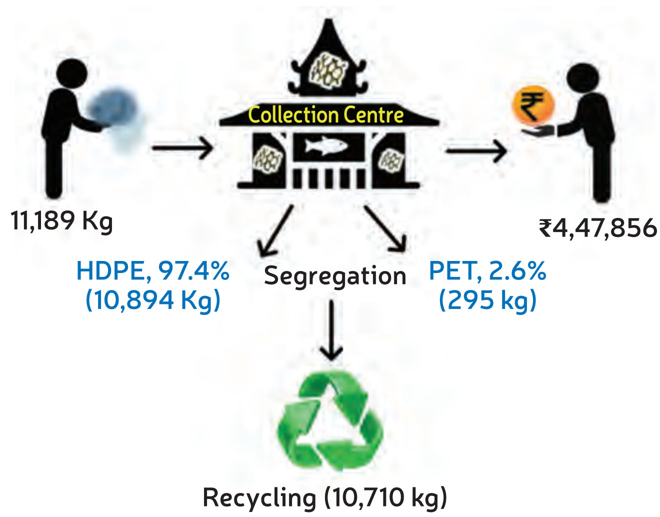


Fig. 12.11: Marine litter recovery and economic benefits: collection impact from Aug 2024 – Jan 2025

Fig. 12.12: Strong community engagement in fishnet collection: 474 transactions recorded

were retrieved from the environment between 17.08.2024 and 31.01.2025.

- Direct benefit to fishermen: 4,47,856 was distributed as financial incentives to fishermen who contributed to the collection efforts, ensuring community engagement in marine conservation (Fig.12.11).
- Active participation: A total of 474 transactions were recorded, reflecting strong participation by local fishing communities (Fig.12.12).

12.8.2. Waste composition and processing

1. Types of waste collected

- 97.4% (10,894 kg) of the collected waste comprised HDPE fishnets, highlighting the prevalence of synthetic fishing gear in marine litter.
- 2.6% (295 kg) consisted of other materials, such as PET plastics.

2. Collection trends

- Collection peaked on 24th January (211 kg), 27th January (136 kg), and 30th January (147 kg), showcasing periodic surges in participation (Fig.12.13).

3. Recycling and repurposing

- 10,710 kg of collected marine litter has already been sent to recyclers.
- The composition of waste sent for recycling closely matches the collected waste, with 97% HDPE and 3% PET being processed into new materials.

4. Impact and future potential

This initiative demonstrates an effective model for circular economy practices in coastal commu-

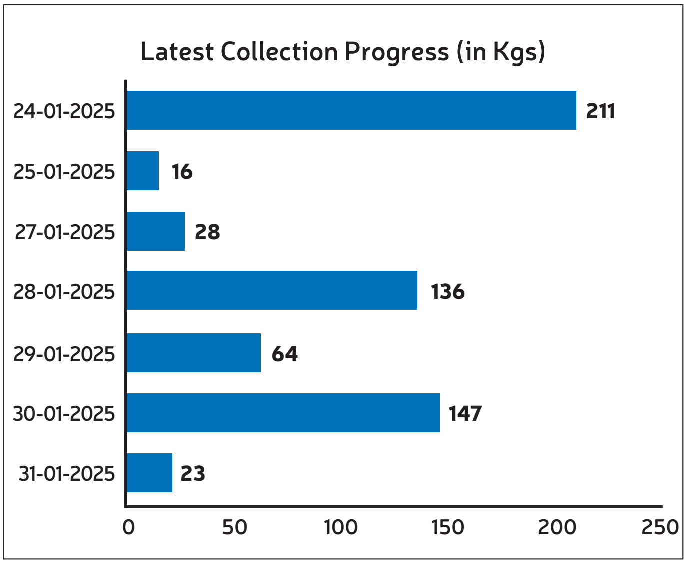


Fig. 12.13: Latest fishnet collection trends in collection centre

nities, turning harmful waste into reusable resources. With continued efforts, fishnet recycling can significantly reduce plastic pollution while supporting livelihoods along the coastline.

12.9. Expansion of fishnet collection centres across Tamil Nadu coastal districts

The government of Tamil Nadu is expanding the fishnet initiatives project to all 14 coastal districts to tackle marine pollution and support coastal communities. This expansion comes under the TN-SHORE (Tamil Nadu Sustainably Harnessing Ocean Resources and Blue Economy), which aims to promote sustainable coastal development, enhance coastal ecosystem resilience and improve the livelihoods of fishing communities. As part of this initiative, a new fishnet collection centre is currently being established at Kovalam, with land identified and stakeholder approvals underway (Fig.12.14). This expansion marks a significant step toward reducing plastic waste, protecting marine biodiversity, and fostering a circular economy along the Tamil Nadu coastline.

Fig. 12.14: Planned expansion of fish net collection centres to all coastal districts of Tamil Nadu

13

INITIATIVES AND EFFORTS TO TACKLE MARINE LITTER

13. INITIATIVES AND EFFORTS TO TACKLE MARINE LITTER

Marine litter is a pressing global challenge with severe consequences for marine ecosystems, biodiversity, human health, and coastal economies. Addressing this issue requires concerted efforts at the global, national, and state levels, each with specific roles and responsibilities. This section provides an overview of key initiatives and actions aimed at combating marine litter, emphasising global frameworks, national efforts, and state-level strategies. These efforts aim to reduce marine litter, prevent its proliferation, and mitigate its environmental impacts. Below is a structured overview of key international instruments and initiatives to address marine litter globally.

13.1. Global Initiatives

Marine litter is a pervasive issue that affects every ocean and coastline worldwide, necessitating coordinated efforts by international, national, and regional stakeholders. Several global-level initiatives have been implemented to reduce marine litter, prevent pollution, and mitigate its impacts on marine ecosystems, biodiversity, and humans. Given below is an overview of prominent international instruments, frameworks, and collaborative programs developed to address this critical environmental challenge (Fig.13.1).

13.1.1. Multilateral partnerships and frameworks

13.1.1.1. Global Partnership on Marine Litter (GPML)

Launched in June 2012 at the United Nations Conference on Sustainable Development (Rio+20), the GPML is led by the United Nations Environment Programme (UNEP). It promotes collaboration among global organizations such as the International Maritime Organization (IMO) and the Food and Agriculture Organization (FAO) to combat marine litter. Key activities include a training package for MARPOL Annexe V and a

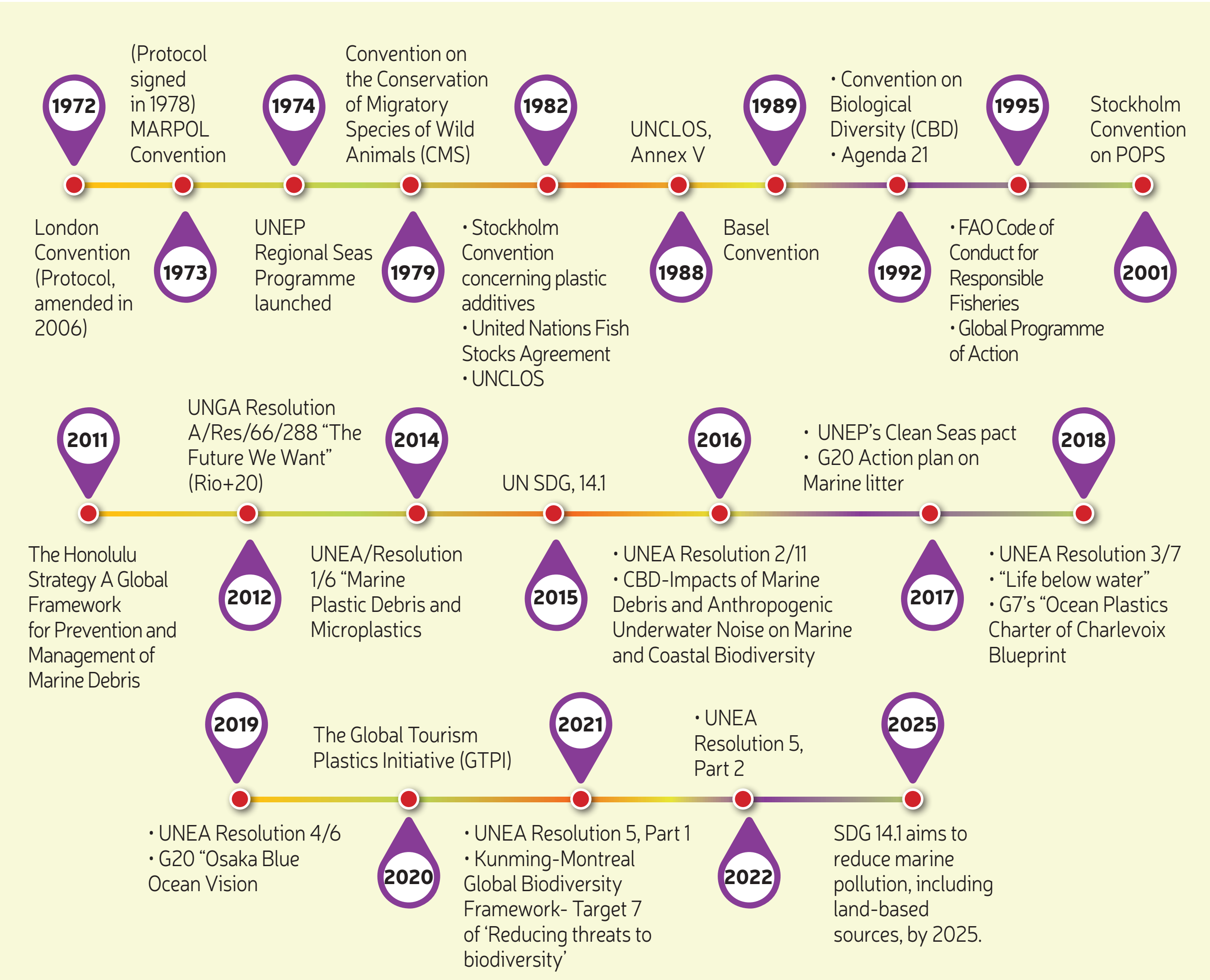


Fig.13.1: Global policy frameworks and initiatives for marine litter and plastic pollution management

Massive Open Online Course (MOOC) on marine litter management.

13.1.1.2. United Nations Environment Management Group (EMG)

Established in 2001, the UN EMG is a system-wide coordination body on environment and human settlements. The EMG Task Team on Marine Litter and Microplastics coordinates efforts across UN agencies, identifying expertise and initiatives to manage marine litter effectively.

13.1.1.3. New plastics economy: global commitment

Launched in October 2018, this initiative is a collaboration between UNEP and the Ellen MacArthur Foundation. It unites private and public sector leaders to transition from a linear plastic economy to a circular economy focused on reuse and recycling.

13.1.2. United Nations campaigns and programs

13.1.2.1. UNEP's clean seas campaign

Launched in 2017, this campaign encourages governments, businesses, and individuals to reduce single-use plastics and adopt sustainable practices to address marine litter.

13.1.2.2. UNEP plastics initiative

Launched in 2018, this initiative includes components like the New Plastics Economy Global Commitment. It focuses on circular economic systems that emphasize reuse and recycling to reduce plastic waste production.

13.1.2.3. Sustainable Development Goal 14 (SDG 14)
SDG 14.1, part of the 2030 Agenda for Sustainable Development (2015), aims to significantly reduce marine pollution by 2025, targeting the preservation and sustainable use of oceans and marine resources. Some of the key targets in this goal are the following:

14.1: By 2025, prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution.

14.2: Sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts and take action for their restoration.

14.4: Effectively regulate harvesting and end overfishing, illegal fishing, and destructive practices to restore fish stocks.

14.5: Conserve at least 10% of coastal and marine areas by 2020, especially areas of ecological importance.

14.a: Increase scientific knowledge, develop research capacity, and transfer marine technology to improve ocean health and biodiversity.

13.1.2.4. UNEA resolutions on marine litter
The United Nations Environment Assembly (UNEA) has played a crucial role in addressing marine litter through its resolutions, emphasizing international cooperation, sustainable practices, and integration into broader environmental agendas.

1. **UNEA resolution 1/6 (2014)** – Recognized marine plastic debris and microplastics as a serious environmental issue and called for international action.
2. **UNEA resolution 2/11 (2016)** – Emphasized the need for policy measures, scientific research, and improved waste management.
3. **UNEA resolution 3/7 (2017)** – Stressed urgent action to prevent and reduce marine litter.
4. **UNEA resolution 4/6 (2019)** – Called for enhanced global monitoring and coordination.
5. **UNEA resolution 4/7 (2019)** – Focused on improving waste management systems.
6. **UNEA resolution 4/9 (2019)** – Aimed at reducing single-use plastic pollution.
7. **UNEA resolution 5 Part 1 (2021)** –Continued emphasis on pollution and environmental issues stemming from plastics.

8. **UNEA resolution 5 Part 2 (2022)** –Addressed critical issues, including pollution and sustainable resource use and highlighted the need for integrated approaches to waste management.

13.1.3. Major global commitments and initiatives

13.1.3.1. Osaka blue ocean vision

Launched at the G20 Summit in Osaka (2019), this vision aims to reduce additional plastic pollution to zero by 2050 through sustainable plastic use, enhanced waste management, and innovative recycling technologies.

13.1.3.2. Ocean plastics charter (Charlevoix blueprint)

Adopted at the 2018 G7 Summit in Canada, this initiative promotes sustainable plastic management with a target of 100% reusable, recyclable, or recoverable plastics by 2030.

13.1.3.3. Kunming-Montreal global biodiversity framework

Adopted in 2022, this framework recognizes the impact of marine litter on biodiversity and calls for reducing plastic flow into marine environments.

13.1.3.4. Global Plastic Treaty (UN Treaty to End Plastic Pollution)

Mandated by United Nations Environment Assembly Resolution 5/14 (UNEA 5/14, 2022), the Global Plastic Treaty is a legally binding international instrument being negotiated to end plastic pollution, including in the marine environment, by 2040. The treaty will address the full lifecycle of plastics from production and design to disposal and aims to curb pollution through circular economy principles, reduction targets, and international cooperation.

Negotiations are led by the Intergovernmental Negotiating Committee (INC), with the final agreement expected by end of 2025.

13.1.4. Targeted initiatives on fishing gear and marine waste

13.1.4.1. FAO Code of Conduct for Responsible Fisheries

Established in 1995, this global framework promotes sustainable fisheries management, including measures to reduce fishing gear waste.

13.1.4.2. Global Ghost Gear Initiative (GGGI)

Launched in 2015, GGGI is the largest alliance dedicated to combating abandoned, lost, or discarded fishing gear (ALDFG).

13.1.4.3. International Whaling Commission (IWC)

In 2018, the IWC adopted a resolution addressing ALDFG and collaborated with GGGI to share data on whale entanglements.

13.1.4.4. London convention and protocol
The 1972 London Convention and its 1996 Protocol regulate waste dumping at sea, prohibiting disposal unless explicitly permitted.

13.1.5. Regional and sectoral frameworks

13.1.5.1. Regional Seas Conventions and Action Plans (RSCAPs)
Since 1974, UNEP's Regional Seas Conventions have fostered regional collaboration to combat marine pollution.

13.1.5.2. Basel convention plastic waste partnership
Launched in May 2019, this initiative under the Basel Convention aims to enhance global cooperation in managing plastic waste.

13.1.6. Research and innovation

13.1.6.1. GESAMP (Group of Experts on the Scientific Aspects of Marine Environmental Protection)
Established in 1969, GESAMP provides scientific advice on marine environmental protection and assesses sea-based sources of marine litter.

13.1.6.2. IAEA NUTEC plastics initiative
Launched in 2019, this initiative uses nuclear technology to track and analyze plastic waste in marine environments.

13.1.7. Industry and civil society efforts

13.1.7.1. International Coastal Clean-up (ICC)
Launched in 1986 by Ocean Conservancy, ICC engages volunteers worldwide in beach and waterway clean-ups.

13.1.7.2. The Honolulu strategy
Established in 2011, this framework aims to reduce the environmental, health, and economic impacts of marine debris through coordinated action, with a focus on prevention, reduction, and management of marine debris.

13.1.7.3. Global Tourism Plastics Initiative (GTPI)
Launched in 2020, GTPI promotes sustainable tourism practices to reduce marine litter.

13.1.8. Regional highlights and programs

- **Europe:** "Fishing for Litter" (2000), EU Single-Use Plastics Directive (2019).
- **UK:** "Clean Seas" Campaign (2017), Responsible Fishing Vessel Standard (RFVS, 2020).
- **USA & Canada:** US Marine Debris Monitoring Program (2009), Canada's Ocean Protection Plan (2016).
- **Thailand:** Moken Guardians of the Sea (2019).
- **Japan:** Marine Litter Reduction Action Plan (2019).
- **Philippines:** Clean Up the Bay Program (2003).
- **Chile & Peru:** Net+Positiva (2017) - recycling fishing nets.
- **Korea:** Marine Debris Buyback Programs (2018).
- **Norway:** Oceanize initiative (2018) - marine plastics recycling.
- **Italy:** ECONYL initiative (2011) - recycling fishing nets into nylon, which is then used to create products like clothing, carpets, and other consumer goods.
- **Greece, Italy, Spain & Thailand:** The EcoALF Foundation's Upcycling the Oceans initiative, which collaborates with fishers and divers to recover marine litter for recycling into fashion products, was launched in 2015.

Efforts to address marine litter at the global level emphasize the need for collaboration among governments, industries, and communities. Multilateral frameworks set the agenda, while innovative solutions from private industries and localized programs demonstrate actionable models for addressing this crisis. Together, these initiatives aim to safeguard marine ecosystems, protect biodiversity, and sustain economies dependent on healthy oceans.

13.2. National initiatives

13.2.1. Policy and framework development

13.2.1.1. National marine litter policy
India is in the process of developing a National Marine Litter Policy through collaborative workshops, stakeholder consultations, and expert discussions. The objective is to establish a comprehensive framework that addresses marine litter, aligns with international commitments, and ensures sustainable marine waste management. The policy integrates environmental, economic, and social considerations to foster a coordinated

national response to marine pollution.

13.2.1.2. Legal framework for plastic waste management

The Environmental Protection Act of 1986 serves as an umbrella framework for environmental protection in India. Key regulations include (Fig.13.2):

National-Level Policies and Initiatives on Plastic Waste Management (India)

- **Plastic Recycling Guidelines (1998)**
  - Provided instructions for the selection, segregation, and safe processing of plastic waste.

- **Recycled Plastics Manufacture and Usage Rules (1999)**
  - Mandated labelling of carry bags as "recycled material" or "virgin plastic."
  - Set a minimum thickness of 20 microns for plastic carry bags.

- **Amendment to Recycled Plastic Rules (2003)**
  - Imposed restrictions on the manufacture and use of virgin/recycled plastics.
  - Required registration of plastic manufacturers with State Pollution Control Boards (SPCBs) or Pollution Control Committees (PCCs).

- **Service Level Benchmarks (2008)**
  - Introduced performance indicators for municipal solid waste management, including segregation and disposal of plastic waste.

- **Plastic Waste (Management & Handling) Rules, 2011**
  - Banned plastic sachets for gutkha, tobacco, and pan masala.
  - Prohibited use of recycled or compostable plastic for food packaging.
  - Required recycled bags to comply with BIS standards and be at least 40 microns thick.

- **Plastic Waste Management Rules, 2016**
  - Increased the minimum thickness of plastic carry bags to 50 microns.
  - Assigned responsibility to plastic waste generators.
  - Introduced Extended Producer Responsibility (EPR) and 'Collect Back' system.
  - Required registration and fee collection from producers/importers.

- **Amendment to PWM Rules (2018)**
  - Proposed phase-out of non-recyclable Multilayered Plastics (MLPs).
  - Introduced a centralised online registrationsystem for PIBOs (Producers, Importers, and Brand Owners).

- **Amendment to PWM Rules (2021)**
  - Introduced steps to eliminate Single-Use Plastics (SUPs).
  - Increased carry bag thickness from 50 to 75 microns (from Sept 30, 2021), and to 120 microns (from Dec 31, 2021).

- **PWM Rules (Amendment), 2022**
  - Revised EPR Guidelines with detailed responsibilities for PIBOs.
  - Mandated online registration and annual reporting through CPCB's EPR portal.
  - Introduced penalties for non-compliance.

- **Single-Use Plastic (SUP) Ban (2022)**
  - Prohibited manufacture, sale, and use of specific identified SUP items.

13.2.1.3. National coastal mission scheme

Launched in 2014 under India's National Action Plan on Climate Change (NAPCC), the National Coastal Mission (NCM) focuses on sustainable coastal management and climate change mitigation. A key initiative under this mission is Beach Environment and Aesthetic Management Services (BEAMS), which promotes beach cleanliness, environmental quality, and community engagement in waste management.

13.2.1.4. National circular economy roadmap for plastic waste reduction (2023)

Developed in collaboration with Australian research organizations, this initiative aims to create a circular economy in India by addressing the entire plastic value chain. Key goals include:

- Reducing landfill plastic waste disposal by 30%

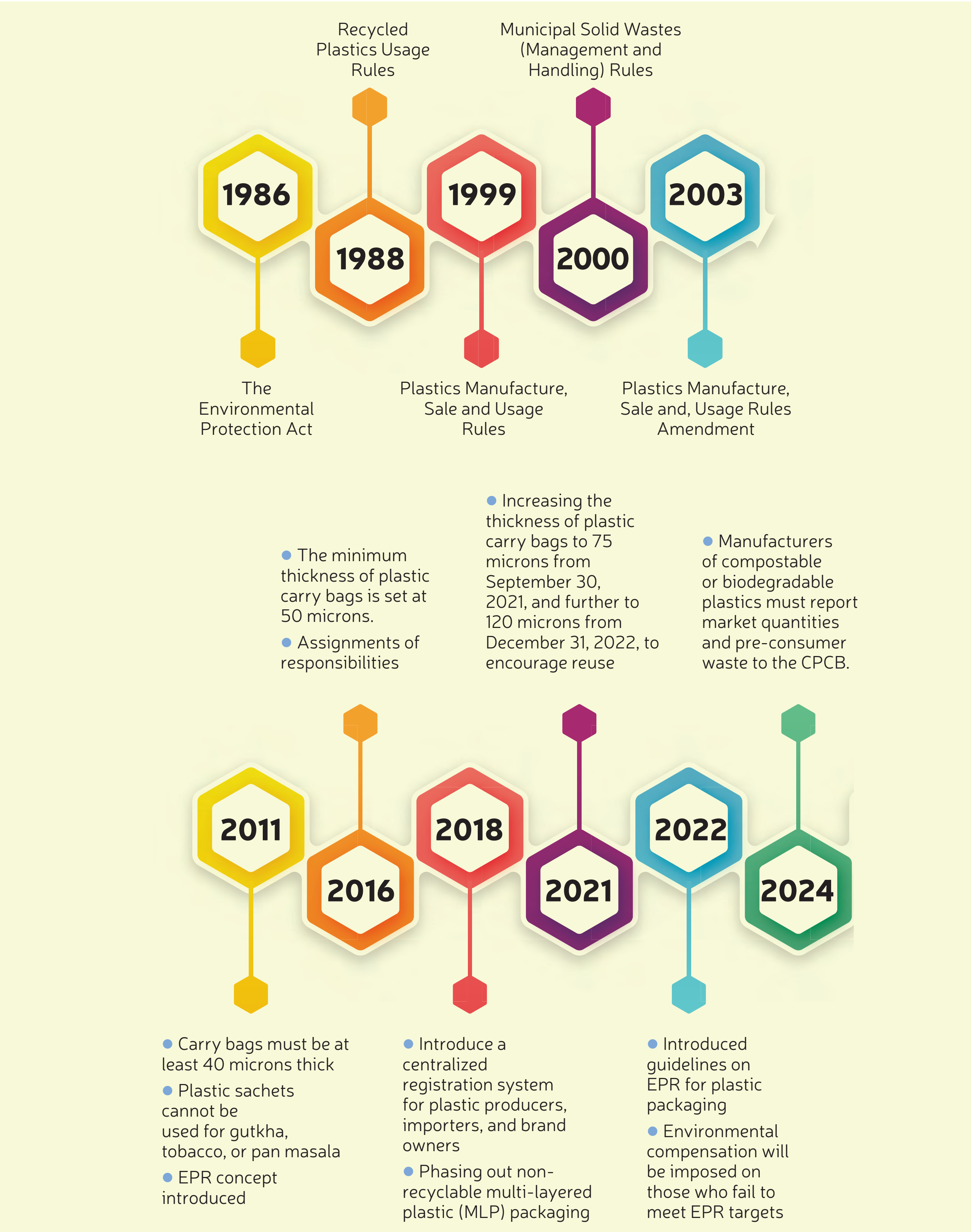


Fig.13.2: Timeline of plastic waste management regulations in India

Fig.13.3: Government initiatives for plastic waste management in India

- Phasing out single-use plastics
- Achieving a 67% recycling rate
- Digitally tracking over 80% of plastic waste by 2035

Fig. 13.3 illustrates a range of government initiatives aligned with this vision, including plastic-to-fuel technologies, extended producer responsibility, bans, public awareness campaigns, and recycling programs.

13.2.2. Clean-up and awareness programs

13.2.2.1. Beach clean-up initiatives

- **National Centre for Coastal Research (NCCR):** Launched in 2018, it conducts beach clean-ups, educational programs, and scientific studies on marine debris, tracking debris patterns and collecting microplastic data.

- **Swachh Bharat Abhiyan (SBA) & Smart Cities Mission:** Launched in 2014 and 2015 respectively, these programs aim to improve sanitation and urban waste management.

- **Blue Flag Certification (2020):** Promotes sustainable development of coastal areas through waste management and beach clean-ups.

- **Swachh-Nirmal Tat Abhiyan (SNTA) (2019):** Focuses on maintaining clean beaches, raising awareness, and engaging local communities in sustainable waste management.

13.2.3. Private sector and community-driven initiatives

13.2.3.1. Industry-led waste reduction programs

- **India Plastics Pact (IPP) (2021):** Works to eliminate problematic plastics, increase recycled content, and transform the plastic lifecycle by 2030.
- **Un-Plastic Collective (UPC) (2019):** Brings together businesses and stakeholders to combat plastic pollution.
- **HCL Foundation & Tamil Nadu Forest Department:** Collaborate to address marine debris and ghost nets in the Gulf of Mannar Marine National Park.
- **SWITCH Asia (PROMISE Project):** Focuses on reducing marine litter in tourism clusters along the Lakshadweep shorelines.

13.2.3.2. Community-based clean-up initiatives

- **TREE Foundation & Indian Coast Guard:** Organize beach clean-ups and awareness programs.
- **Grow Billion Trees:** Removed over 10,000 kg of plastic waste from India's coastlines in 2023.
- **Versova Beach Clean-up (Mumbai):** One of the world's largest beach clean-up initiatives.
- **Andaman and Nicobar Clean-Up Drive (2022):** Engaged local organizations in cleaning tourist beaches.
- **Beach Please (Puducherry, 2018):** Mobilizes communities for beach clean-ups.
- **Coastal impact (Goa):** Promotes responsible tourism and marine conservation.
- **Environmentalist Foundation of India (EFI, 2007):** Engages communities in restoring beach, lake, and pond ecosystems.

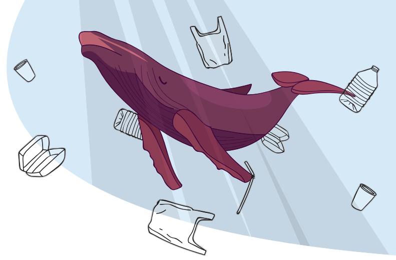
13.2.4. Increasing the value chain of ghost nets

- **DSM Engineering Materials (Pune):** Converts ghost nets into surfboards, recycling about 2,000 tonnes annually.
- **Green waves environmental solutions (Visakhapatnam) & WWF India:** 'Ghost Gear Upcycling' project (since 2021) transforms ghost nets into bracelets, pouches, doormats, and pots.

- **Projects REPLAN (2020 - KVIC):** Converts plastic waste into eco-friendly bags and other sustainable products.

13.2.5. Development of plastic alternatives

- **DharakshaEcosolutions (Delhi):** Produces biodegradable packaging from agricultural stubble waste using mycelium, decomposing in 60 days.
- **SKYi Innovations (Pune) & FKuR (Germany):**



Produces compostable biopolymers, such asBio-Flex®, for flexible packaging.

- **Defence Research and Development Organisation (DRDO):** Develops biodegradable cutlery from agricultural waste and renewable polymers, composting in 90 days.
- **National Institute of Ocean Technology (NIOT):** Produces plastic films from marine seaweed.
- **CPCB & Waste management agency of Goa:** Processes non-biodegradable waste and supports compostable plastic manufacturing.

13.2.6. Technological innovations in waste management

- **Ricron Panels:** Transforms multilayer plastics into recyclable panels and roofing sheets, reducing landfill waste.
- **Ishitva Robotic Systems:** Uses AI, machine learning, and Internet of Things (IoT) for efficient waste sorting.
  - **YUTA:** AI sorting robot
  - **NETRA:** Machine vision system
  - **SUKA:** Air sorter for improving sorting accuracy

13.2.7. Education, awareness, and outreach on marine litter

- **BEAMS (Beach Environment and Aesthetic Management Service):** Focuses on pollution control, beach safety, and environmental education.
- **Swachh Sagar, Surakshit Sagar:** Launched the “Eco Mitram” app to encourage community engagement in coastal cleanliness efforts.
- **National education policy (2020):** Mandates environmental education, integrating marine litter awareness into school curricula.
- Climate Literacy and Marine Litter Management (CLMLM): Increased local awareness of climate change and marine litter by 62%, enhancing community resilience.

13.3. Tamil Nadu initiatives

13.3.1. Tamil Nadu coastal restoration mission

The Tamil Nadu government has launched the Tamil Nadu Coastal Restoration Mission, marking it as the fourth mission-oriented project initiated by the state, following the Climate Change Mission, Green Tamil Nadu Mission, and Wetland Mission. This initiative focuses on four key thematic areas:

- **Enhancing coastal biodiversity:** Protecting and restoring marine ecosystems.
- **Safeguarding coastlines:** Implementing measures to prevent coastal erosion and degradation.
- **Improving livelihoods of coastal communities:** Supporting sustainable livelihoods through eco-friendly practices.
- **Reducing pollution in coastal regions:** Addressing sources of marine litter and pollution.

As part of this mission, the government aims to certify 11 beaches as Blue Flag Beaches, which adhere to strict ecological and cleanliness standards. The project also seeks to engage youth from coastal communities in activities such as establishing Plastic Waste Management facilities, eliminating ALDFG, and developing circular economy solutions to combat pollution. This includes identifying areas with significant plastic waste issues and installing capture booms in polluted river and coastal ecosystems.

13.3.2. TN Fishnet Initiative (TNFI)

One of Tamil Nadu’s key initiatives in addressing fisheries-related marine litter is the Tamil Nadu Fishnet Initiative (TNFI), launched in 2024 by the Tamil Nadu Pollution Control Board (TNPCB). This program aims to establish an organized system for collecting and recycling discarded fishnets, thereby reducing ALDFG pollution. Under this initiative, the first fishnet collection centre was set up in Kasimedu, Chennai, with plans for expansion to other coastal districts of Tamil Nadu. The initiative is detailed extensively in Chapter 12, which outlines its objectives, implementation, and impact.

13.3.3. Ban on Single-Use Plastics (SUPs)

To combat plastic pollution, the Government of Tamil Nadu implemented a ban on single-use plastics of all thicknesses on June 25, 2018, effective from January 1, 2019, under the Environment (Protection) Act, 1986, via G.O (Ms.) No. 84. This ban prohibits the manufacture, sale, storage, supply, transport, and use of 14 categories of single-use plastics throughout the state. Tamil Nadu is recognized as one of the few states to enforce such a comprehensive ban.

13.3.4. Enforcement of SUP Ban

To ensure compliance with the SUP ban, the government has implemented various measures, including inspections, confiscation of banned plastics, and the imposition of fines. Instances of non-compliance have been identified in commercial entities and local markets, leading to actions against violations of Plastic Waste Management rules.

13.3.5. Meendum Manjappai campaign

Launched in December 2021, the MeendumManjappai Campaign aims to raise awareness about alternatives to plastic and promote the use of traditional cloth bags (manjappai).

13.3.6. Manjappai vending machine

The Tamil Nadu Government introduced Manjappai Vending Machines (MVMs) under the Meendum Manjappai Campaign to promote eco-friendly cloth bags and reduce single-use plastic consumption. The initiative began with installations at key locations, including five machines at the Madurai Bench of the Madras High Court on November 24, 2022, and an automatic Manjappai dispensing machine in Perambalur on January 8, 2024. By September 2024, a total of 188 vending machines had been installed across markets and public buildings, distributing nearly 385,000 cloth bags to encourage sustainable alternatives and responsible consumer behaviour.

13.3.7. Manjappai awards

The Tamil Nadu Pollution Control Board (TNPCB) plans to recognize outstanding contributions through the Manjappai Awards, which will be given to schools, colleges, and commercial establishments promoting alternatives to single-use plastics (Fig.13.4).

13.3.8. Digital initiatives

As of June 6, 2023, TNPCB launched the Meen-

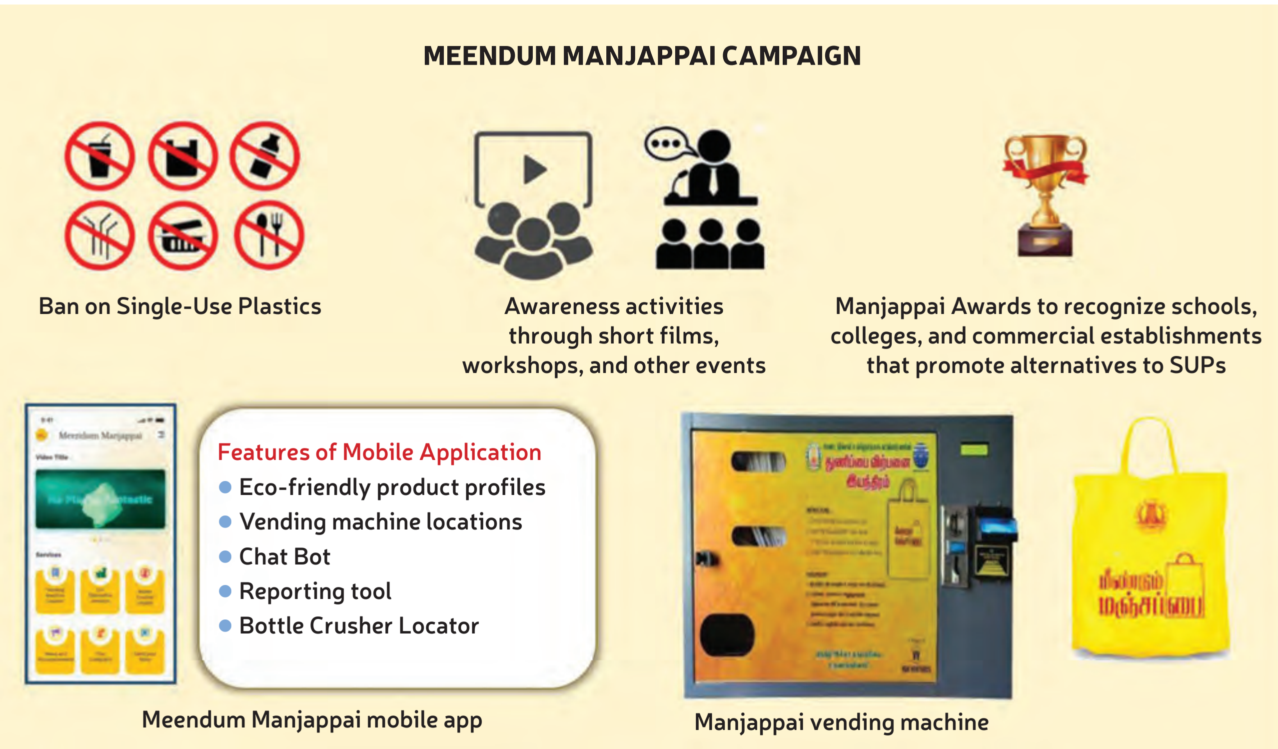


Fig.13.4: Meendum Manjappai: Promoting Eco-Friendly Alternatives and Sustainable Practices

dum Manjappai mobile app and website, featuring profiles of manufacturers of sustainable alternatives, geo-tagged locations for vending machines, and tools for reporting SUP violations.

13.3.9. Manjappai Brigade

On October 30, 2023,TNPCB launched the Manjappai Brigade in Chennai to raise awareness about SUP violations. This initiative expanded with a second brigade in March 2024 and the “Green Brigade” in tourist areas in August 2024. The “Blue Brigade,” focusing on marine pollution, started on August 27, 2024. Collectively, these brigades have travelled over 74,000 kilometers and reached more than 5,400 locations to promote sustainable alternatives to SUPs.

13.3.10. Enviro Solvers Hackathon

The Enviro Solvers Hackathon 2023, organized by the Tamil Nadu Pollution Control Board (TNPCB) as part of Mission LiFE, focused on innovative solutions for environmental issues like water scarcity and single-use plastics. The event attracted over 1,000 registrations, with 800 applications shortlisted. Winning solutions included “Washing Machines: A Hybrid Approach towards Water Management” and “Bioinspired Hydrogel Capsules for Increased Water Retention,” developed by various organizations. Notable contributors included Dynamic Megaceutics, Chemfab Alkalis Limited, Sigma En Tech, SRMIST, and Anna University. Winners were honoured on June 5, 2023, during World Environment Day celebrations.

13.3.11. G20 beach cleaning event

The G20 Mega Beach Clean-up Event in Tamil Nadu took place on May 21, 2023, from 7:00 a.m. to 9:00 a.m. at three beaches: Besant Nagar Beach in Chennai, Kovalam Beach in Chengalpattu, and Manakudi Beach in Kanniyakumari. Organized by the National Centre for Sustainable Coastal Management (NCSCM) and GIZ, the initiative aimed to raise awareness about maintaining clean beaches and promote community involvement. Fish-shaped trash bins were installed to implement circular economy solutions to prevent marine litter.

13.3.12. Clean Kovalam project

The Clean Kovalam Project, initiated by Positive Change for Marine Life (PCFML), focuses on reducing marine litter through beach cleaning campaigns, educational programs for local communities, and enhancements to waste management. In addition to the Clean Kovalam Project, PCFML has been involved in other initiatives in the region, such as the Waste to Wealth program, which commenced in 2018. This program trains local marginalized women to collect various waste streams from households, aiming to promote sustainable waste management practices.

13.3.13. Trash interceptors

Tamil Nadu has partnered with The Ocean Cleanup, a Dutch non-profit organization, to deploy innovative trash interceptors in rivers across 14 coastal districts, including Chennai. This initiative is part of the Tamil Nadu Coastal Restoration Mission, aiming to combat plastic pollution in rivers and coastal areas. The deployment of these interceptors began in January 2024, to prevent plastic waste from entering the oceans.

13.3.14. Beach cleaning machines

Asia’s largest beach, namely the Marina, is polluted due to the improper disposal of litter by its visitors. Manual and mechanical methods of litter removal involving the use of beach cleaning machines (the Surf Rake) were employed. The machine can collect materials such as broken glass, polythene sheets or bags, plastics, foams, ropes, syringes, cigarette butts, pop-tops, straws, cans, tar balls, stones, sea grass, seaweed, fish, wood, coconut, fishnets, etc. and transfer them to dumping trucks, which are later transferred to waste segregation facilities.

13.3.15. Circular economy solutions

The National Centre for Sustainable Coastal Management (NCSCM) has been working on circular economy approaches to manage marine litter, including technology-driven solutions to close material cycles and promote resource efficiency. In collaboration with GIZ, the “Circular Economy Solutions Preventing Marine Litter” project has been operational since 2022. The project focuses

Fig.13.5: Sustainable actions for ocean conservation: small changes, big impact!

on innovative solutions to reduce plastic leakage in riverine and marine ecosystems, enhancing compliance, digital tracking, and technological solutions. NCSCM is actively contributing to reducing marine litter and promoting sustainability.

13.3.16. Collaboration with international organizations

The Mannar Region Systemic Solutions (MARESSOL) project, funded by the Norwegian Retailers Environment Fund (NREF), is an international collaboration aimed at addressing ALDFG in the Gulf of Mannar and Palk Strait. Key partners include SALT Sustainability (Norway), the International Union for Conservation of Nature (IUCN) (Sri Lanka), the Suganthi Devadason Marine Research Institute (SDMRI) (Tamil Nadu, India), and the Lanka Environment Fund (LEF). The project focuses on sustainable fisheries solutions to reduce marine debris and emphasizes the need for comprehensive policies, including gear marking, mandatory loss reporting, extended producer responsibility, gear design improvements, and litter removal incentives. This collaboration aims to mitigate marine pollution and promote sustainable practices in the region, highlighting the significance of international partnerships in addressing environmental challenges.

13.3.17. Community engagement and awareness programs

Various community engagement initiatives are implemented to raise awareness about marine litter and its impacts. These programs involve local schools, NGOs, and community groups to foster a collective responsibility towards maintaining clean coastal environments.

13.3.18. Research and monitoring

There are several ongoing research and monitoring efforts taken to assess the effectiveness of the initiatives in place. They include collection of data on marine litter sources, types, and quantities, which will inform future strategies and policies.

These initiatives collectively reflect Tamil Nadu's strong commitment to combating marine litter through a multi-pronged strategy that combines policy enforcement, technological innovation, and active community participation. From digital platforms and public awareness brigades to hackathons, beach clean-up drives, waste management innovations, and international collaborations, the state has embraced an integrated approach to coastal conservation.

Equally important are everyday behavioural changes at the individual level. Simple actions such as refusing single-use plastics, choosing reusable and eco-friendly alternatives, disposing of waste responsibly, and supporting sustainable policies play a critical role in reducing marine pollution (Fig.13.5). By practicing mindful consumption, purchasing in bulk, avoiding products with microbeads, opting for natural fiber clothing, and raising awareness through discussions, individuals can become catalysts for change.

14

RECOMMENDATIONS AND FUTURE DIRECTIONS

14. RECOMMENDATIONS AND FUTURE DIRECTIONS

Marine plastic pollution is a pervasive global crisis, posing serious threats to ecosystems, human health, economies, and overall quality of life. Its impact on climate change is significant, occurring at every stage of the plastic lifecycle—from production and transportation to degradation. Every country must take immediate and effective measures to confront this urgent issue. Our existing knowledge of the causes of marine litter and potential solutions provides a strong foundation for proactive action. Tackling marine litter effectively requires a robust, multi-faceted approach that emphasizes prevention, reduction, and mitigation. This involves not only individual actions but also transformative changes across industries, communities, and decisive government policy.

The adoption of innovative cleanup technologies, promotion of sustainable consumption practices, and fostering a global ethos of accountability are critical steps forward. The urgency for action is paramount—the health of our oceans depends on it.

Among the various sources of marine litter, Abandoned, Lost, or Discarded Fishing Gear (ALDFG) represents a particularly critical concern. ALDFG poses significant threats to marine ecosystems, biodiversity, and the livelihoods of coastal communities. Addressing this challenge requires integrated and forward-looking strategies that combine technological innovation, policy reform, and community participation. Sustainable fishing practices, improved gear retrieval and recycling

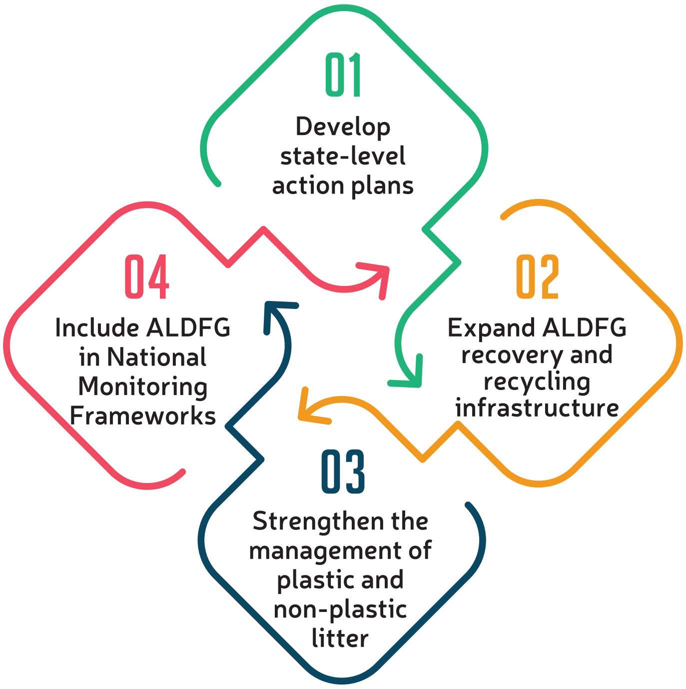


Fig. 14.1: Priority Interventions for ALDFG and Marine Litter Management

mechanisms and the adoption of eco-friendly gear designs are essential components of this response. Equally important is the active engagement of local communities, fishing industries, and policymakers in developing a circular economy for fishing gear—one that minimizes environmental impact while ensuring long-term sustainability. By prioritizing the management of ALDFG within broader marine litter strategies, regions like Tamil Nadu can protect their coastal ecosystems and promote the welfare of fishing-dependent communities.

14.1. Strengthening India's Draft National Marine Litter Policy: Strategic directions

India's 11,098.81 km coastline supports diverse ecosystems and millions of coastal livelihoods, and yet it faces increasing threats from marine plastic pollution. Studies estimate that over one-third of marine debris in India originates from land-based sources, including single-use plastics and discarded fishing gear, with an annual growth rate of 8.5% in marine litter load (Sambandam et al., 2024).

In response, the Ministry of Earth Sciences (MoES) formally unveiled the Draft National Marine Litter Policy during the ClimateNXT 2025 event on World Environment Day. Developed by the National Centre for Coastal Research (NCCR) in 2024, the framework outlines source-specific strategies and multi-tiered interventions across sectors such as tourism, fisheries, and waste management (Sambandam et al., 2024; Mongabay India, 2025). The draft emphasises critical areas such as ALDFG management, beach zoning, stakeholder engagement, and extended producer responsibility.

However, the policy has not been released for public review yet (as of July 2025). While the Draft National Marine Litter Policy outlines a solid strategic framework, its success will ultimately depend on robust implementation, including legislative backing, adequate financial support, community participation, and scientific monitoring to ensure meaningful outcomes for India's marine ecosystems.

14.2. Strategic recommendations based on study findings

The baseline beach litter survey revealed key trends in litter type, source, and spatial distribution. Based on these findings, the following specific recommendations are proposed (Fig. 14.1).

14.2.1. Develop state-level action plans

Following the adoption of the National Marine Litter Policy, each coastal state should be mandated to formulate a State Marine Litter Management Plan. In Tamil Nadu, district-wise shoreline litter accumulation has been assessed through the TNFI project, and a pilot ALDFG collection center has been established (at Kasimedu). Based on its success, Hon'ble Chief Minister of Tamil Nadu, during World Environment Day on 05th June 2025, has announced 14 more ALDFG Collection centers covering 14 coastal districts. However, these initiatives should be scaled up and institutionalized across the Tamil Nadu coast, covering more fishing villages under hubs through the state plan. The plan should include hotspot mapping (e.g., fishing gear accumulation zones), periodic beach clean-up strategies, and dedicated funding for establishing ALDFG recovery and recycling infrastructure. Other coastal states should be encouraged to replicate this model based on region-specific litter data and management needs.

14.2.2. Expand ALDFG recovery and recycling infrastructure

The present study found that 47.5% of beach litter consisted of Abandoned, Lost, or Discarded Fishing Gear (ALDFG), and 94.81% of surveyed fishers reported the absence of proper disposal facilities at landing sites. To address this, scaling up ALDFG collection and recycling infrastructure across Tamil Nadu's 14 coastal districts is essential, building on the successful pilot measure initiated at Kasimedu Fishing Harbour, which recovered 11,189 kg of nets and provided 4.47 lakh in incentives across 474 transactions. These centres should be integrated into formal coastal waste management systems and operated in collaboration with fishers' associations, recyclers, and net dealers. Introducing digital tracking systems will enhance transparency and accountability.

14.2.3. Include ALDFG in National Monitoring Frameworks

ALDFG should be recognized as a distinct category within national marine litter monitoring systems. Establishment of gear-specific indicators, reduction targets, and fisher-reported loss tracking through regular surveys should be considered. Integration of data from buy-back schemes, recovery centres, and digital systems will support policy alignment and global reporting obligations.

14.2.4. Strengthen management of general plastic and non-plastic litter

In addition to ALDFG, the study found that general plastic debris (39.64%) and non-plastic waste (12.9%) together accounted for half of the total beach litter, mainly from land-based sources such as tourism, dumping, and riverine inputs. Due to various anthropogenic pressures, coastal zones are highly sensitive and vulnerable to climate change. To address this, coastal waste management systems must be improved through better segregation, more frequent collection, and stricter enforcement of plastic waste regulations. Covered bins should be installed and signage displayed at beaches and harbours. Public outreach campaigns and targeted clean-ups at litter entry points will further reduce pollution.

14.3. Recommendations for policymakers and coastal stakeholders on marine litter and ALDFG management

In addition to field-driven actions, the following strategic priorities are proposed in alignment with recent policy commentaries (Sambandam et al., 2024; Mongabay India, 2025) and emerging

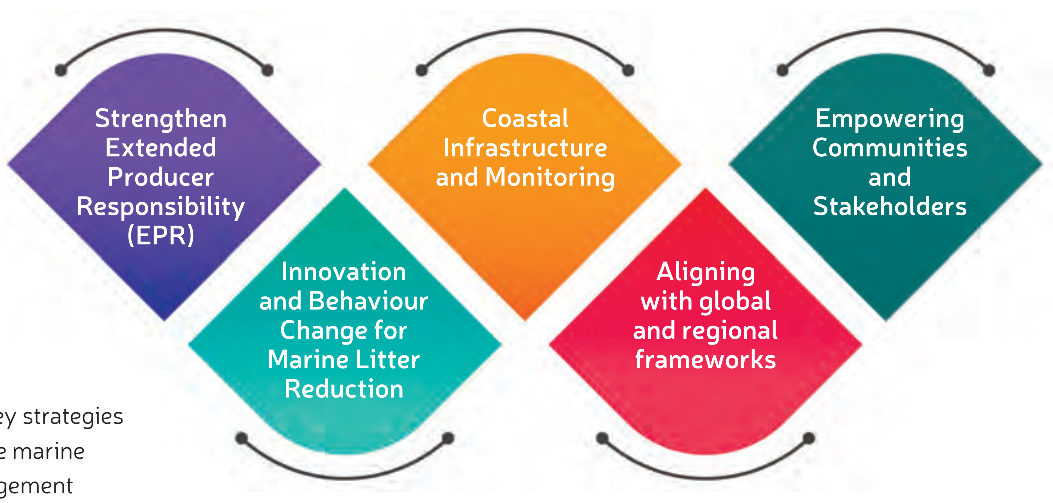


Fig. 14.2: Key strategies for effective marine litter management

global initiatives, including the United Nations Global Plastics Treaty (under negotiation), the Food and Agriculture Organization's Global Ghost Gear Initiative (FAO-GGGI, 2023), the Coordinating Body on the Seas of East Asia (COBSEA, 2023), and the Global Partnership on Marine Litter (GPML, UNEP, 2024) (Fig.14.2).

14.3.1. Strengthen Extended Producer Responsibility (EPR)

While the 2024 amendments to India's Extended Producer Responsibility (EPR) framework have improved traceability and accountability for land-based plastic packaging (MoEFCC, 2024), marine-specific plastic waste, particularly ALDFG, remains inadequately addressed. In light of global best practices and evolving policy discussions, the following strategic expansions to India's EPR framework may be considered to reduce marine plastic leakage:

- Expand EPR coverage to include marine-use plastics such as fishing nets, floats, ropes, buoys, and packaging associated with marine operations. International guidance, such as the FAO's Voluntary Guidelines on the Marking of Fishing Gear (FAO, 2019), calls for improved traceability of fishing gear to prevent ghost gear accumulation.

- Mandate port-level reporting and digital tagging of fishing gear by manufacturers and importers. Each gear unit introduced into the marine environment should carry a Quick Response code (QR code) or Radio Frequency Identification tag (RFID tag) indicating its origin, owner, type, and deployment location. Such systems are increasingly being piloted and recommended globally to improve monitoring and facilitate recovery of lost gear (FAO-GGGI, 2023; UNEP-GPML, 2024).

- Establish a marine litter offset credit system, modelled after carbon credit markets, whereby companies or fishers who exceed plastic waste limits can finance certified ghost gear recovery or recycling initiatives. Similar offset mechanisms are under discussion in international platforms like the United Nations Global Plastic Treaty negotiations (UNEP, 2023) and COBSEA's regional action framework (COBSEA, 2023).

These recommendations align with the vision of transitioning toward a circular economy for plastics in fisheries and aquaculture (EU, 2022) and can help India set a precedent for integrating ocean-bound plastics into national producer responsibility frameworks.

14.3.2. Coastal infrastructure and monitoring

Improving coastal infrastructure is essential for intercepting land- and sea-based litter, minimizing leakage into the marine environment, and strengthening the region's ability to respond to pollution events.

- Install floating barriers and debris traps at strategic locations, such as river mouths, creeks, and estuarine zones. Cities like Chennai have deployed trash booms in the Cooum and Adyar rivers, reportedly capturing thousands of tonnes of floating debris annually (AP News, 2022). Similar technologies are used by AlphaMERS and other firms under public-private partnerships.

- Invest in decentralized coastal and island waste management systems, including source segregation, decentralized treatment units, and safe disposal facilities tailored to remote fishing villages and tourist hotspots. These interventions are consistent with recommendations from the Clean Currents Coalition and coastal pollution management frameworks that emphasize local-scale solutions to reduce plastic leakage (Benioff Ocean Initiative, 2021; Ocean Conservancy, 2020).

- Equip fishing harbours, beaches, and ports with plastic collection stations, EPR stalls, and decentralized recycling hubs. These hubs improve recovery, traceability, and accountability in managing ALDFG as recommended by UNEP (2021a) and FAO (2018).

- Introduce mandatory QR/RFID-based digital tracking and gear marking systems for fishing nets and equipment, aligned with Sea-based Marine Plastic Litter (SBMPL) Actions 5.1.2 and 5.2.7. Pilot these systems in Tamil Nadu in collaboration with national agencies such as Central Institute of Fisheries Nautical and Engineering

Training (CIFNET)/Central Institute of Fisheries Technology (CIFT) to implement the same. This would enhance traceability, retrieval and accountability in managing ALDFG.

- Mandate the installation of microplastic filters at coastal industrial effluent discharge points and commercial laundry units, supporting the need for filtration technology. Studies indicate that the high microplastic load in Indian rivers and estuaries is due to untreated effluent and microfiber shedding (Lechthaler et al., 2021; Ramasamy et al., 2025).

- Establish open-access data-sharing platforms to track marine litter hotspots, seasonal deposition patterns, and potential transport pathways. This would support early warning, evidence-based planning, and real-time coordination among agencies (GESAMP, 2016).

- Strengthen early warning and response systems for events such as plastic pellet leakage, container losses, and post-disaster debris surges, through improved coordination among the authorities of Coastal Zone Management, Port and disaster response agencies.

14.3.4. Empowering communities and stakeholders

Coastal communities, especially fisherfolk, Self Help Groups (SHGs), and Non-Government Organizations (NGOs), play a key role in addressing marine litter. Their active participation supports early detection, clean-up, and long-term waste management. The following community-driven actions help to support marine litter mitigation and stakeholder empowerment.

- Establish community-operated fishing gear hubs, following guidance from FAO and GGGI's Best Practice Framework, to facilitate gear recovery, reduce loss, and promote reuse or recycling of nets and floats (GGGI, 2023).

- Conduct training for fisherfolk and coastal workers in marine litter monitoring, net retrieval, and safe disposal methods—following protocols promoted by KIMO International and FAO on community-based ghost gear recovery programs (KIMO International, 2020).

- Institutionalize reporting systems through Panchayats or SHGs to flag ALDFG hotspots and incidents of plastic pellet leakage. Community-driven reporting tools like those endorsed by FAO-GGGI support localized identification of marine litter accumulation zones (GGGI, 2023).

- Support micro-enterprises focused on gear repair, plastic reuse, and small-scale recycling aligned with circular economy principles emphasized in recent policy commentaries (Sambandam et al. 2024) and consistent with blue economy and livelihood-oriented best practices.

- Engage schools and colleges in beach clean-ups and citizen science programs to build local awareness and data collection capacity, complementing global community marine stewardship initiatives (Ocean Conservancy, 2020).

14.3.5. Innovation and behaviour change for marine litter reduction

Reducing marine litter requires a combination of regulation, innovation, and public engagement, especially in sectors like tourism, fishing, and coastal infrastructure. The following evidence-based strategies align with national initiatives:

- Phase out single-use plastic items in coastal zones, under the Plastic Waste Management (Amendment) Rules, 2022, which mandate restrictions on items like cutlery, straws, and sachets, empowering local authorities to enforce bans in critical coastal areas (MoEFCC, 2022).

- Promote Blue Flag eco-certification for beaches and ports, supported by MoEFCC's Beach Environment & Aesthetics Management Services (BEAMS), which helps develop sustainable infrastructure and ensures zero plastic litter (Press Information Bureau (PIB), 2022).

- Apply behavioural nudges at tourist and pilgrimage sites: Evidence from behavioural science and tourism studies supports the effectiveness of nudges such as QR code pledges, visual cues, and gamified waste bins to raise responsible disposal among visitors.

- Support coastal innovation hubs for sustainable technologies: Under initiatives like Swachh-Sagar, Surakshit Sagar, marine institutes and technical colleges are encouraged to innovate solutions, including biodegradable fishing gear, floating barriers, microplastic filters, and smart bins—as documented in national action plans and innovation reports (UN GloLitter National Action Plan for India, IMO/FAO-Norway GloLitter Partnerships Project, 2024).

- Encourage/mobilize support for plastic-free events and sustainable coastal tourism practices (MoHUA, 2022) under Swachh Bharat Mission–Urban 2.0, eco-tourism subsidies, and CSR-driven cleanup programs.

14.3.6. Aligning with global and regional frameworks

Marine litter is a transboundary challenge. India should continue to:

- Align with the upcoming UNEP Global Plastics Treaty and commit to national targets and reporting (UNEA 5.2, 2022).

- Participate in regional marine litter action plans, including the South Asia Co-operative Environment Programme (SACEP), Regional Marine Litter Action Plan and cooperation through the Bay of Bengal Programme (BOBP) (SACEP, 2019).

- Share best practices and data with platforms like Global Partnership on Marine Litter (GPML) and Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) (UNEP/IOC/UNESCO, 2017), which provide evidence-based guidance and assessment frameworks for marine litter monitoring and policy responses.

14.4. Strengthening community - industry partnerships for marine litter reduction

Effective marine litter management requires inclusive participation from coastal communities, industries, and civil society. Collaborative approaches, including Public–Private Partnerships (PPPs), are essential to scale up waste recovery systems, promote innovation, and ensure long-term behavioural change (Fig.14.3).

14.4.1. Empowering coastal communities

- Launch awareness campaigns in local languages highlighting marine litter impacts on livelihoods, food safety, and tourism, following FAO GGGI guidance (FAO GGGI Annual Report, 2023)

- Promote community-led beach clean-ups and zero-waste coastal villages, aligned with India's MeriLiFE campaign and Swachh Sagar, Surakshit

Fig. 14.3: Strengthening community and industry partnerships for marine litter reduction

Sagar initiatives, which mobilized widespread local involvement in coastal clean-ups (MoES, 2022).

- Introduce net buy-back schemes and reward-based disposal incentives, ensuring responsible recovery of ALDFG, modelled on successful initiatives and evidence from the present study.

14.4.2. Engaging industries

To reduce marine litter from industrial sources, the involvement of key stakeholders, including plastic manufacturers, fishing gear producers, maritime industries, and tourism operators, would actively support circular economy approaches and Extended Producer Responsibility (EPR) schemes. The following actions are proposed:

- Promote eco-friendly innovation, including the development and use of biodegradable nets and marine-safe packaging, as encouraged under the Plastic Waste Management Rules, 2022 (MoEF-CC, 2022).

- Strengthen EPR mechanisms for marine-use plastics using tools like port-side disclosure of gear types, QR-coded tracking systems for fishing nets, and buy-back models where used or recovered gear can be returned to manufacturers or designated recyclers.

- Encourage the repurposing of recovered ALDFG by linking with local recycling enterprises and cooperatives to produce value-added items such as doormats, ropes, and handicrafts. This recommendation draws from the successful model implemented in Visakhapatnam, where organizations such as Green Waves Environmental Solutions partnered with WWF India to upcycle ghost nets (Green Waves/WWF India, 2021–2022).

14.4.3. Expanding Public–Private Partnerships (PPPs)

- Establish PPP-based marine waste recovery and recycling centres in coastal districts, with investment from CSR arms of maritime industries (UNEP, 2021).

- Support start-ups and university-industry collaborations focused on gear tracking technologies, microplastic filtration systems, and litter upcycling championed under the Swachh Sagar, Surakshit Sagar framework and national innovation challenges.

- Launch youth innovation challenges through technical institutes, motivating cost-effective marine litter solutions and enhanced public engagement.

14.5. Vision for a sustainable marine environment: future prospects

A sustainable marine future envisions clean, resilient oceans that sustain biodiversity, buffer climate impacts, and support coastal livelihoods. Achieving this vision requires integrated actions at global, national, and state levels, rooted in science, equity, circular economy principles, and innovation (Fig.14.4).

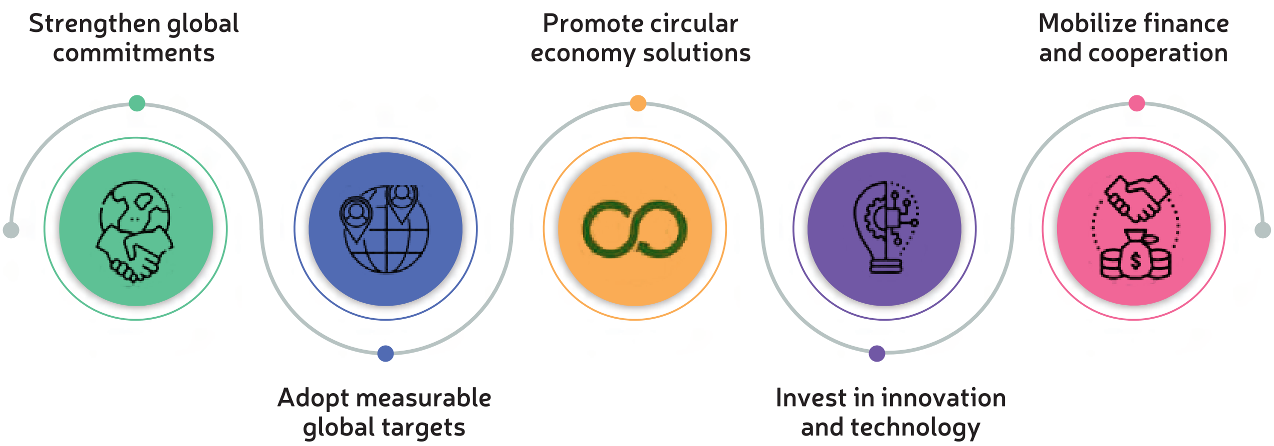


Fig. 14.4: Global framework for tackling plastic pollution

14.5.1. Global prospects: A unified approach for marine conservation

Marine litter is a transboundary issue that demands coordinated international responses. India should:

14.5.1.1. Strengthen global commitments by aligning national policies with:

- SDG 14.1: By 2025, prevent and significantly reduce marine pollution, particularly from land-based activities (UN, 2015).
- The Global Plastics Treaty, being negotiated under the United Nations Environment Assembly (UNEA 5.2) to end plastic pollution by 2040 (UNEP, 2022).
- The Global Ghost Gear Initiative (GGGI), coordinated by FAO, targeting ALDFG (FAO-GGGI, 2022).

14.5.1.2. Adopt measurable global targets, such as:

- UNEP's Global Plastic Pollution Agreement, which aims to eliminate plastic leakage into the ocean by 2040 (UNEP, 2022).
- International Maritime Organization (IMO) goal: Reduce marine litter from ships significantly by 2025 (IMO, 2018).
- EU Marine Strategy Framework Directive (MSFD): Achieve Good Environmental Status (GES) of EU seas by 2030 (EC, 2008).
- Global Partnership on Marine Litter (GPML): Calls for a measurable reduction in marine litter impacts by 2030 (UNEP, 2021).
- Related SDGs:
  - SDG 14.1 - Prevent marine pollution
  - SDG 12.5 - Reduce waste generation through prevention, reduction, and recycling
  - SDG 9.4 - Upgrade infrastructure for sustainable industrialization (UN, 2015) (Fig.14.5).

14.5.1.3. Promote circular economy solutions through:

- Use of biodegradable fishing gear and marine-safe materials.
- Mandatory Extended Producer Responsibility (EPR) for marine-use plastic and ghost gear.
- International design standards for eco-friendly gear (FAO-GGGI, 2022).

14.5.1.4. Invest in innovation and technology, including:

- AI-based debris detection and robotic retrieval.

- Floating booms and bubble barriers for riverine litter interception.

- Satellite-based mapping of ALDFG hotspots (UNESCO-IOC, 2021).

14.5.1.5. Mobilize finance and cooperation, such as:

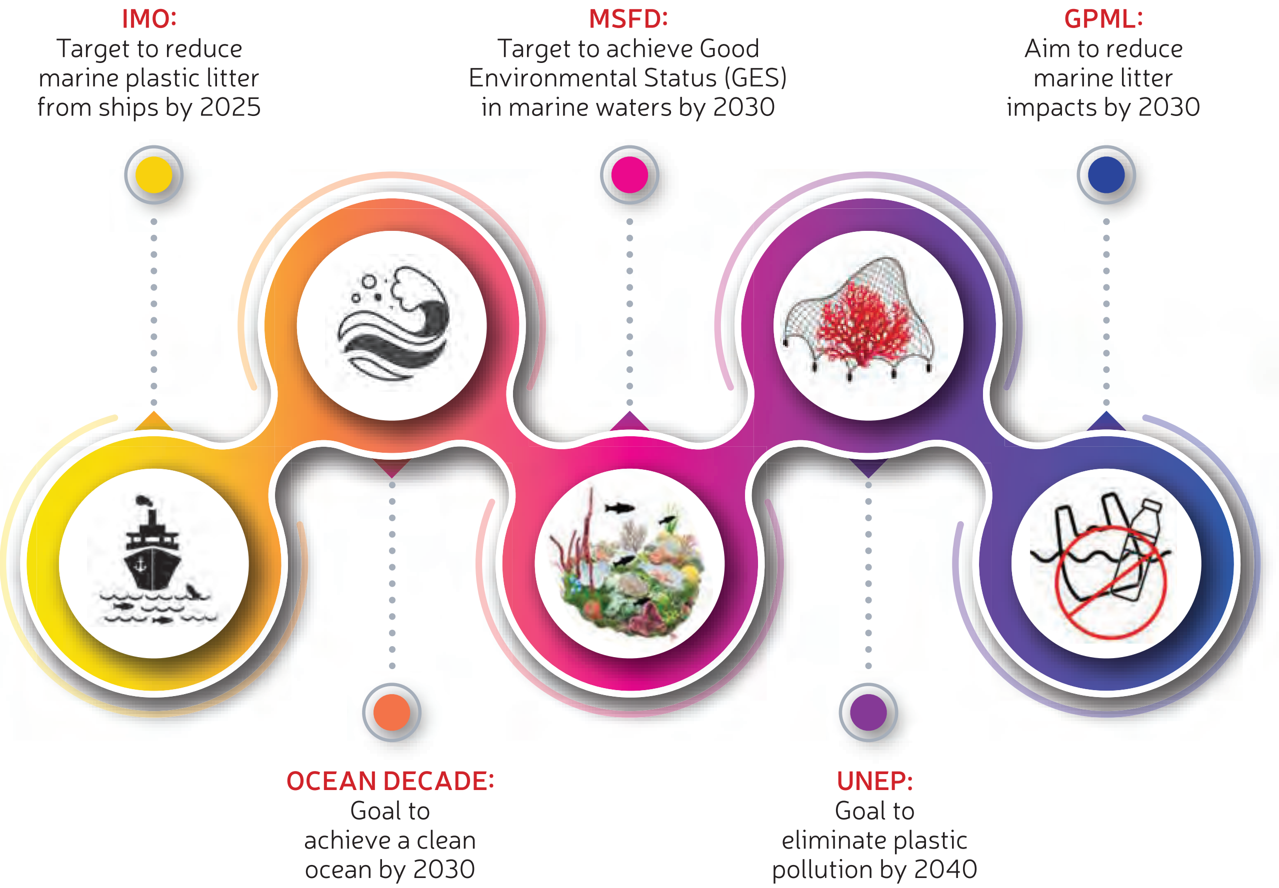
- Leveraging multilateral funding (e.g. Global Environment Facility [GEF], UNEP, World Bank) for national and regional marine litter programmes.

- Enhancing South-South Cooperation, particularly for Small Island Developing States (SIDS) and low-income coastal nations (UNEP, 2022).

These global targets and frameworks must be integrated into India's long-term marine litter policy to ensure alignment with international commitments, including the goal to eliminate plastic pollution by 2040 under the UNEA-endorsed Global Plastics Treaty and related multilateral frameworks.

14.5.2. National prospects: Strengthening India's response to marine litter

India's extensive coastline of 11,098.81 km—with important coastal habitats supporting rich marine biodiversity, dense coastal populations, and varied commercial and livelihood activities including fishing—presents both challenges and opportunities for managing marine litter, particularly ALDFG (Fig.14.6). The recent release of the Draft National Marine Litter Policy (NMLP) by the Ministry of Earth Sciences (MoES) in June 2025 marks a significant step in national-level recogni-



14.5: Global efforts and targets to combat marine litter and plastic pollution

14.6: Strengthening India's approach to marine litter reduction

tion of this issue. Though not yet open for public review, the draft policy outlines strategic priorities across data generation, prevention, circular economy, and stakeholder engagement (Sambandam et al., 2024).

Findings from the present study and the ongoing national initiatives point to multiple areas where India's response could be strengthened:

14.5.2.1. Policy alignment and regulatory gaps
While the Plastic Waste Management Rules (2016, amended 2022) provide a framework for Extended Producer Responsibility (EPR) and source reduction of plastic waste, there is currently no specific national regulation addressing Abandoned, Lost or otherwise Discarded Fishing Gear (MoEFCC, 2022). The recent release of the Draft National Marine Litter Policy(MoES, 2025) reflects growing policy recognition of marine litter, including the need for prevention, monitoring, and circular economy approaches. More specifically, it is not yet clear how ALDFG issues will be addressed or integrated with India's existing legal and management systems for coastal areas.

India's coastal management is framed through two principal structures:

- Integrated Coastal Zone Management (ICZM): A dynamic planning approach intended to harmonize ecological conservation, community welfare, and coastal development. Funded by the World Bank, the ICZM Programme operates under the Ministry of Environment, Forest and Climate Change (MOEFCC); it emphasizes multi-sectoral coordination and adaptive governance along India's coasts (NCSCM/SICOM, World Bank 2010–2015)

- Coastal Regulation Zone (CRZ) Notifications: These are statutory rules issued under Section 3 of the Environment (Protection) Act, 1986, first notified in 1991 and revised in 2011 and 2019. CRZ regulations classify coastal stretches into CRZ I to CRZ IV zones and strictly regulate development and land-use within designated buffer zones from the high tide line (from as small as 50 m to 500 m, depending on zone)

At present, no publicly available document clarifies how ALDFG management strategies align with ICZM and CRZ frameworks, making it difficult to assess regulatory coherence. Enhancing coordination across these governance structures is essential to address marine litter and ghost gear effectively at the national level.

14.5.2.2. Institutional and infrastructure needs
India currently lacks a nationwide collection, segregation, and recycling framework for ALDFG. While pilot initiatives such as those by Green Waves Environmental Solutions in Visakhapatnam have demonstrated the feasibility of localized gear recovery and repurposing (Green Waves / WWF India, 2021–2022), there is no standardized national mechanism for gear buyback, deposit-refund schemes, or drop-off infrastructure at fishing harbours and landing centres. Notably, in Tamil Nadu, the Tamil Nadu Pollution Control Board (TNPCB) has started the establishment of discarded fishing net collection and recycling centres to support sustainable fishing gear disposal and incentivize fishers through collection credits (TNPCB, 2024). These initia-

tives highlight a promising model, but coverage remains limited. To effectively reduce ghost gear accumulation, such decentralized models must be scaled up through institutional coordination, dedicated funding, and public-private partnerships.

14.5.2.3. Technological and circular economy opportunities

There is growing interest in innovative technologies to improve fishing gear traceability and reduce gear loss, including QR-coded net tagging, RFID systems, satellite-based vessel monitoring, and the use of biodegradable or compostable fishing gear (FAO-GGGI, 2022; UNEP, 2021). However, these solutions largely remain at the pilot or research stage, with limited implementation in Indian fisheries due to high costs, lack of regulatory mandates, and limited fisher awareness or training. Similarly, circular economy models that involve upcycling ALDFG into consumer products (e.g., footwear, textiles, accessories) are currently spearheaded by NGOs, start-ups, and CSR-funded programs, often in partnership with coastal communities (WWF-India, 2023;The Hindu, 2021). Despite their promise, these efforts are mostly fragmented and small-scale, lacking integration into national waste management or blue economy frameworks. Scaling up these models requires enabling policies, public-private partnerships, and targeted innovation support.

14.5.2.4. Stakeholder and market engagement

Although awareness of the environmental and economic impacts of ALDFG is gradually increasing among some fisher communities, formal mechanisms for retrieval and responsible disposal remain limited. Fishery cooperatives often lack the institutional and financial capacity to implement circular economy approaches or Extended Producer Responsibility (EPR) schemes for end-of-life gear. Likewise, industry stakeholders, including gear manufacturers and seafood exporters, have not yet systematically integrated into product stewardship or marine-specific EPR frameworks.

A study from coastal Kerala reported that an average of 11.6% of deployed fishing gear is lost annually, and 90% of fishers surveyed were either unaware of or lacked access to any structured gear recovery or disposal mechanisms (Daniel et al., 2022). The key factors contributing to gear loss as indicated by the findings of the present fisherfolk survey conducted across Tamil Nadu—include net snagging on underwater obstructions, adverse weather, entanglement with other gear, and displacement by trawlers. Critically, 94.81% of fishers complained about the absence of dedicated gear disposal facilities, and 90.81% anticipated increased ALDFG over the next five years in the absence of proper waste management systems.

14.5.2.5. Research and monitoring

Despite growing attention to marine debris in India, there is currently no centralized national database on the quantities, spatial distribution, or recovery rates of ALDFG. Most of the available information is fragmented and originates from site-specific or short-duration studies led by academic institutions or non-governmental organizations. Systematic baseline mapping, especially in high-risk zones such as offshore fishing grounds, coral reefs, and seagrass habitats, is lacking. The absence of coordinated, long-term monitoring limits India's ability to assess trends, evaluate risks to biodiversity and fisheries, and develop targeted management or retrieval interventions.

14.5.3. State-Level Prospects: strengthening marine protection initiatives

The extensive coastline and the vibrant marine economy of Tamil Nadu call for targeted state-level interventions to mitigate marine litter, particularly ALDFG and enhance coastal health and fisheries sustainability(Fig.14.7).

14.5.3.1. Developing a state-level marine litter management framework

Tamil Nadu has taken significant initial steps toward structured marine litter governance. Key efforts include the Tamil Nadu Fishnet Initiative (2024), the establishment of a pilot fishnet recovery centre (Kasimedu), and active partici-

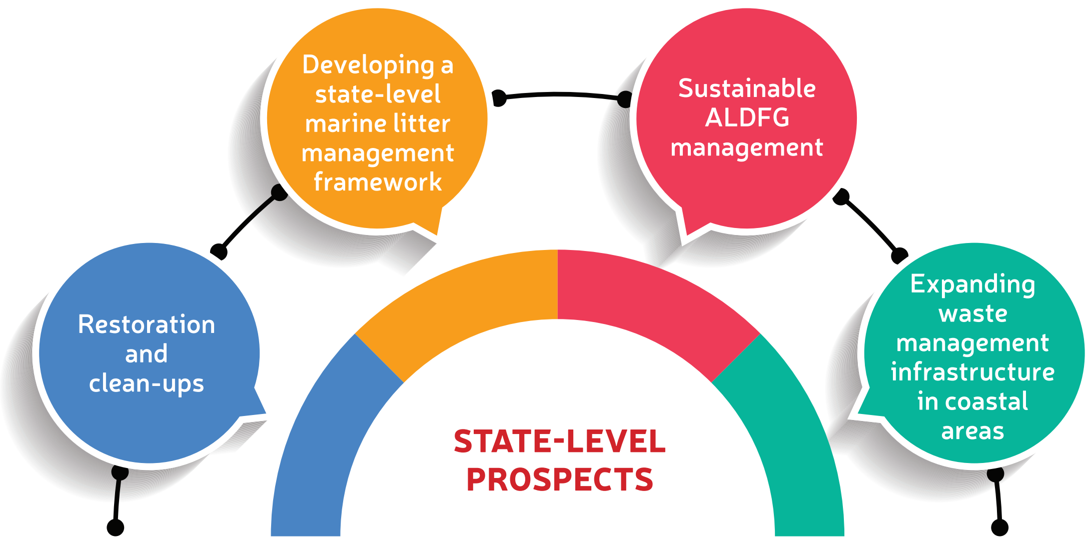


Fig. 14.7: State-Level Prospects: Enhancing marine protection and ALDFG management

pation in national coastal clean-up programs such as Swachh Sagar, Surakshit Sagar (TNPCB, 2024; MoES, 2022).

The Tamil Nadu Sustainably Harnessing Ocean Resources and Blue Economy (TN-SHORE) Project (G.O. Ms. No. 11, Environment, Climate Change, and Forests Department, dated 10.01.2024), identifies Pollution Abatement as one of its five thematic priorities. This component includes the identification of plastic waste hotspots, the development of digital waste exchange platforms, ALDFG management in river systems, and investments in climate-smart coastal villages These objectives offer scope for integration with Tamil Nadu's ongoing ALDFG initiatives and can help strengthen an integrated approach to marine litter management under a broader coastal sustainability framework.

These initiatives lay the groundwork for formulating a State Marine Litter Action Plan, aligned with the objectives outlined in the Draft National Marine Litter Policy (MoES, 2024). Additionally, a State-Level Marine Litter Task Force, aligned with SBMPL Actions, may be established under the joint coordination of the Tamil Nadu Pollution Control Board, the Department of Environment of Climate Change and Forests, and the Department of Fisheries, with representation from the Tamil Nadu State Coastal Zone Management Authority, research institutions, and local NGOs actively involved in marine conservation

14.5.3.2. Expanding waste management infrastructure in coastal areas

In Tamil Nadu, a fish net collection centre has been established at Kasimedu Fishing Harbour by the Tamil Nadu Pollution Control Board (TNPCB). This facility enables the segregation and safe storage of ALDFG and serves as a model for localized marine litter mitigation. Building on this initiative, TNPCB has proposed setting up similar centres in other coastal districts to strengthen decentralized ALDFG management. However, dedicated recycling facilities to process the collected nets into reusable materials are yet to be developed in the state. At the national level, the Central Pollution Control Board (CPCB), under its 2024 coastal waste management initiative, has issued technical guidelines and proposed financial incentives to promote the establishment of fish net and plastic recycling units, particularly near Blue Flag Beaches and major fishing hubs. Tamil Nadu is eligible under this initiative, and its participation could support a transition from collection-focused systems to a comprehensive ALDFG recycling infrastructure.

It is recommended to establish a standardized collection framework in all major harbours in Tamil Nadu, with clearly defined Standard Operating Procedures (SOPs) for the collection, storage, and transfer of ALDFG and other general marine plastic litter (MPL).

14.5.3.3. Strategies for sustainable ALDFG management

To ensure long-term and sustainable management of ALDFG in Tamil Nadu, a multi-pronged strategy is recommended. First, community-based ALDFG retrieval programmes can be introduced, wherein fishers are incentivized through gear return credits—a model successfully adopted in several Asian and European countries to promote fisher-led recovery efforts (UNEP, 2021). Second, the state can promote the use of eco-friendly fishing practices by providing subsidized biodegradable gear and enforcing gear marking regulations to improve traceability, in line with the FAO's Voluntary Guidelines for the Marking of Fishing Gear (FAO, 2022). Third, fostering innovation through support to marine biotechnology start-ups and Micro, Small, and Medium Enterprises (MSMEs) in Tamil Nadu can catalyze the development of biodegradable materials, recyclable nets, and gear recovery technologies, aligning with India's Blue Economy Vision (MoES, 2021). Fourth, to enhance surveillance and targeted intervention, monitoring of ALDFG hotspots can be expanded using GIS tools, drones, and remote sensing techniques, as recommended by the National Centre for Coastal Research (NCCR, 2023). These integrated strategies would enable Tamil Nadu to transition towards a science-based, circular, and community-driven approach to ALDFG management.

14.5.3.4. Restoration and clean-ups: removing and preventing litter accumulation

Restoration of critical coastal ecosystems such as mangroves, coral reefs, and seagrass beds plays a vital role in mitigating marine litter. These ecosystems act as natural filters that trapfloating plastics, reduce shoreline erosion, and sustain biodiversity and fisheries (MoEFCC, 2020; UNEP, 2021). In addition, rehabilitation of coastal dunes in erosion-prone areas can reduce the backflow of wind-blown litter into the marine environment (MoEFCC, 2020). Promoting community-led clean-up drives, modelled on successful initiatives like Swachh Sagar, Surakshit Sagar encourages citizen participation, especially among fishing communities and school children, to maintain cleaner coasts (NCCR, 2023). Strengthening shoreline waste management infrastructure, including the installation of covered dustbins, signage, and waste segregation units at fish landing centers and tourist beaches, is essential to prevent re-entry of waste into the ocean (MoEFCC, 2022).

14.6. Actionable steps for ALDFG management

Based on current gaps, international best practices, and regional needs, a phased action plan is proposed to guide the effective management of ALDFG in Tamil Nadu (Fig.14.8).

14.6.1. Short-Term (1-3 years)

Focus: Awareness, collection, enforcement, and stakeholder collaboration

- **School-based environmental education:** Collaborate with the National Council of Educational Research and Training (NCERT) and the Tamil Nadu School Education Department to integrate marine litter, ALDFG impacts, and sustainable fishing topics into school curricula. This will raise early environmental stewardship and awareness among students.

- **Multilingual media and mobile outreach:** Develop multilingual campaigns through community radio, local television, posters, and mobile apps to engage diverse coastal communities. These platforms can disseminate information on ALDFG hazards, best practices for gear disposal, and available reporting/recovery systems.

- **Community awareness:** Launch targeted awareness campaigns to educate fishers on the environmental and economic impacts of ALDFG.

- **Citizen-led monitoring:** Encourage citizen science groups and community members to partici-

Fig. 14.8: Actionable steps for ALDFG management: Short-, Mid- and Long-Term goals

pate in ALDFG hotspot mapping, gear retrieval reporting, and awareness efforts. Leveraging local knowledge and participatory tools can improve data accuracy and strengthen community engagement, and long-term stewardship.

- **ALDFG projects:** Implement more collection and recycling initiatives in high-priority fishing hubs, modelled on the Kasimedu fishnet collection centre.

- **Regulatory enforcement:** Strengthen enforcement of laws against illegal disposal of fishing gear to ensure compliance, especially in hotspot zones.

- **Incentive-based retrieval:** Introduce a verified buy-back or gear return scheme where fishers are rewarded for retrieving ALDFG, supported by Extended Producer Responsibility (EPR) contributions or government marine conservation budgets.

- **Data-linked incentive system:** A data-linked incentive system can be initiated using a mobile application to track recovered ALDFG, disbursed incentives, and recycling outcomes-ensuring transparency and enabling future expansion across coastal regions.

- **Multi-stakeholder task forces:** Form local ALDFG task forces involving fishers, harbour authorities, fisheries officials, NGOs, and scientists to coordinate retrieval, data collection, and community engagement.

- **Gender-inclusive participation:** Promote the engagement of fisherwomen in ALDFG collection, segregation, and recycling activities as part of livelihood empowerment under the blue economy framework. This promotes inclusive coastal development and acknowledges the valuable contributions of women in managing marine resources.

14.6.2. Mid-Term (3-5 years)

Focus: Infrastructure, livelihood creation, and sustainable technology adoption

- **Advanced technologies:** Upgrade ALDFG clean-up efforts using drone surveillance and AI-based tracking systems to locate and map ghost gear accumulation zones efficiently.

- **Recycling infrastructure:** Establish regional gear recycling centers in collaboration with the fishing industry and local authorities. These centers should process recovered gear into reusable materials or commercial products, encouraging circular economy practices.

- **Mobile collection units:** Deploy mobile ALDFG collection and sorting units in remote coastal villages. These units can support on-site segregation, temporary storage, and awareness campaigns.

- **Skills development and entrepreneurship:** Develop vocational training on gear repair and recycling to create local jobs.

- **Eco-friendly fishing gear:** Promote the transition to biodegradable and environmentally sustainable fishing gear by offering financial subsidies, technical training, and pilot demonstrations in partnership with fishing cooperatives and gear manufacturers.

- **Research and innovation support:** Encourage the state's institutions affiliated to Central Institute of Fisheries Technology (CIFT) and Indian Council of Agricultural Research(ICAR) to lead innovations related to sustainable fishing gear. Promote field trials of biodegradable fishnets and gear retrieval technologies (e.g., smart buoys), to support eco-friendly gear transitions and smart fishing practices.

- **Public-Private Partnerships (PPPs):** Promote partnerships between the government and private companies to set up and run gear recycling units, test biodegradable fishing gear, and support awareness programs. Involving the private sector can bring innovation, more funding, and help scale up long-term solutions for managing ALDFG effectively.

14.6.3. Long-Term (5-10 years)

Focus: Strategic integration and global alignment

- **Blue economy linkage:** Integrate ALDFG recovery into Tamil Nadu's broader blue economy strategy for inclusive and sustainable growth.

- **ALDFG Reduction targets:** Achieve a 50% reduction in ALDFG presence along Tamil Nadu's key coastal zones, using current baseline values derived from this assessment.

- **Circular economy integration:** Fully incorporate ALDFG into a state-wide circular economy, ensuring complete recovery and recycling of fishing gear.

- **Marine innovation hubs:** Establish marine innovation hubs for gear redesign, reuse, and circular fishing practices.

- **Global leadership:** Position Tamil Nadu as a regional and global leader in sustainable marine resource management by aligning ALDFG strategies with international conventions (like FAO Voluntary Guidelines, UNEA resolutions) and showcasing best practices through knowledge exchange platforms.

Figure 14.9 illustrates a structured approach integrating short-, mid-, and long-term interventions for ALDFG management through coordinated efforts in net waste collection, gear recycling, financial incentives, awareness building, and cross-sectoral partnerships. These actions collectively support enhanced fisheries sustainability, environmental governance, and economic resilience.

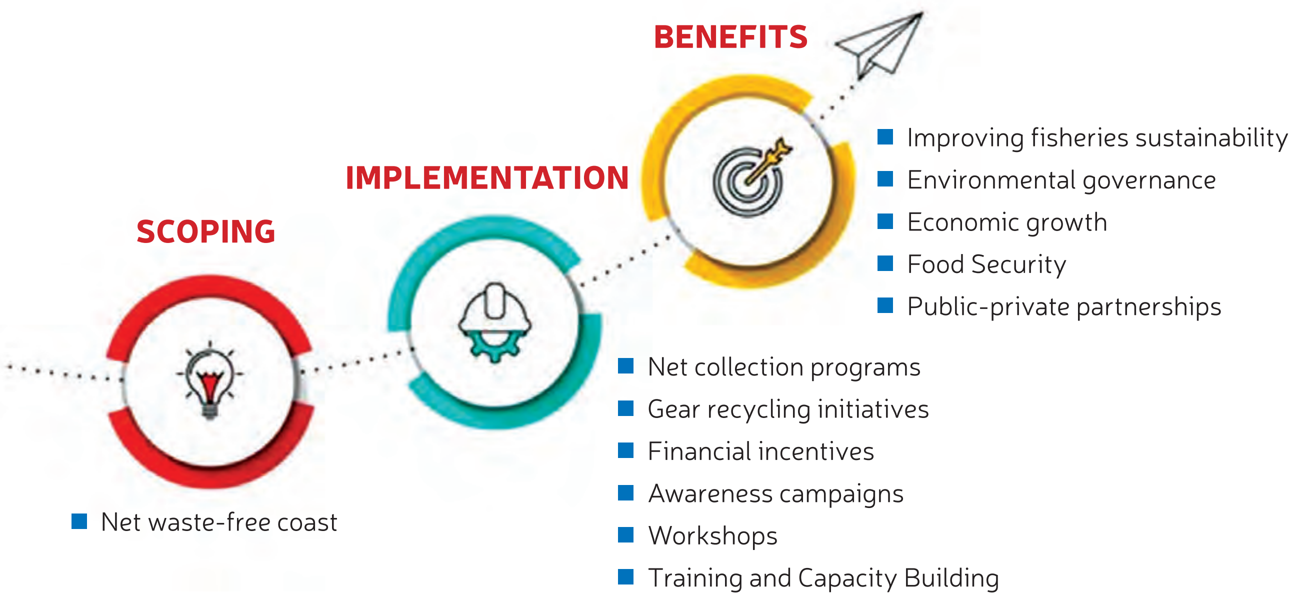


Fig. 14.9: Phased strategy for achieving a net waste-free coastline in Tamil Nadu

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REFERENCES

1. Abalansa, S., El Mahrad, B., Icely, J., & Newton, A. (2021). Electronic Waste, an Environmental Problem Exported to Developing Countries: The GOOD, the BAD and the UGLY. Sustainability, 13(9), 5302. https://doi.org/10.3390/su13095302

2. Al Nahian, S., Rakib, M. R. J., Haider, S. M. B., Kumar, R., Walker, T. R., Khandaker, M. U., & Idris, A. M. (2022). Baseline marine litter abundance and distribution on Saint Martin Island, Bay of Bengal, Bangladesh. Marine Pollution Bulletin, 183, 114091. https://doi.org/10.1016/j.marpolbul.2022.114091

3. Alkalay, R., Pasternak, G., & Zask, A. (2006). Clean-coast index-A new approach for beach cleanliness assessment. Ocean & Coastal Management, 50(5-6), 352-362. https://doi.org/10.1016/j.ocecoaman.2006.10.002

4. Apete, L., Martin, O. V., & Iacovidou, E. (2024). Fishing plastic waste: Knowns and known unknowns. Marine Pollution Bulletin,205, 116530. https://doi.org/https://doi.org/10.1016/j.marpolbul.2024.116530

5. AP News. (2022). Indian cities use floating trash barriers to reduce plastic pollution. Retrieved from https://apnews.com/article/technology-netherlands-india-pollution-f659cc1e89bac5294f0a6478e64bbbfe

6. Arabi, S., Neehaul, Y., Sparks, C. (2023). Impacts and Threats of Marine Litter in African Seas. In: Maes, T., Preston-Whyte, F. (eds) The African Marine Litter Outlook. Springer, Cham. https://doi.org/10.1007/978-3-031-08626-7_3

7. Arzey, A. K., McGregor, H. V., Clark, T. R., Webster, J. M., Lewis, S. E., Mallela, J., McKay, N. P., Fahey, H. W., Chakraborty, S., Razak, T. B., and Fischer, M. J. (2024). Coral skeletal proxy records database for the Great Barrier Reef, Australia, Earth Syst. Sci. Data, 16, 4869–4930, https://doi.org/10.5194/essd-16-4869-2024

8. Ashrafy, A., Liza, A. A., Islam, M. N., Billah, M. M., Arafat, S. T., Rahman, M. M., & Rahman, S. M. (2023). Microplastics Pollution: A Brief Review of Its Source and Abundance in Different Aquatic Ecosystems.

Journal of Hazardous Materials Advances, 9, 100215. https://doi.org/10.1016/j.hazadv.2022.100215

9. Aydın, C., Güven, O., Salihoğlu, B., & Kideys, A. E. (2016). The influence of land use on coastal litter: An approach to identify abundance and sources in the coastal area of Cilician Basin, Turkey. Turkish Journal of Fisheries and Aquatic Sciences, 16(1), 29–39. https://doi.org/10.4194/1303-2712-v16_1_04

10. Balazs, G., (1985). Impact of ocean debris on marine turtles: entanglement and ingestion. In: Shomura, R. S., Yoshida, H. O. (Eds.), Proceedings of the Workshop on the Fate and Impact of Marine Debris. Southwest Fisheries Center, Honolulu Laboratory, National Marine Fisheries Service, Honolulu, Hawaii, USA, 387–429

11. Barik, S., Swain, M., Mohanty, P. K., Padhi, S. R., Kar, P. K., & Mishra, P. (2024). Beach litter pollution along the odisha coast: Composition, abundance, biodiversity impact and management practices. Regional Studies in Marine Science, 71, 103421. https://doi.org/10.1016/j.rsma.2024.103421

12. Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical transactions of the royal society B: biological sciences, 364(1526), 1985-1998. https://doi.org/doi:10.1098/rstb.2008.0205

13. Barría-Herrera, J., Vergara-Cortés, H., Contreras-López, M., & Rangel-Buitrago, N. (2021). A seasonal comparison of litter impacts along the Viña del Mar - Concón coastal strip, Valparaiso region of Chile. Marine Pollution Bulletin, 172, 112854. https://doi.org/10.1016/j.marpolbul.2021.112854

14. Bauer, F., T. D. Nielsen, L. J. Nilsson, E. Palm, K. Ericsson, A. Fråne, and J. Cullen. 2022. Plastics and climate change breaking carbon lock-ins through three mitigation pathways. One Earth 5(4):361–376.

15. Behera, D. P., Kolandhasamy, P., Sigamani, S., Devi, L. P., & Ibrahim, Y. S. (2021). A preliminary investigation of marine litter pollution along Mandvi beach, Kachchh, Gujarat. Marine Pollution Bulletin,165, 112100. https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.112100

16. Bekova, R., & Prodanov, B. (2024).Spatio-temporal variation in marine litter distribution along the Bulgarian Black Sea sandy beaches: amount, composition, plastic pollution, and cleanliness evaluation. Frontiers in Marine Science, 11, 1416134. https://doi.org/10.3389/fmars.2024.1416134

17. Bettencourt, S., Costa, S., & Caeiro, S. (2021). Marine litter: A review of educative interventions. Marine Pollution Bulletin, 168, 112446. https://doi.org/10.1016/j.marpolbul.2021.112446

18. Bettencourt, S., Freitas, D. N., Lucas, C., Costa, S., & Caeiro, S. (2023). Marine litter education: From awareness to action. Marine Pollution Bulletin, 192, 114963. https://doi.org /10.1016/j.marpolbul.2023.114963

19. Benioff Ocean Initiative. (2021). Plastic Waste Capture in Rivers. Clean Currents Coalition. Retrieved from https://cleancurrentscoalition.org

20. Bhuyan, M. S. (2022). Effects of Microplastics on Fish and in Human Health. Frontiers in Environmental Science, 10, 827289. https://doi.org/10.3389/fenvs.2022.827289

21. Biswas, T., & Pal, S. C. (2023). Emerging threats of microplastics on marine environment: A critical review of toxicity measurement, policy practice gap

and future research direction. Journal of Cleaner Production, 434, 139941. https://doi.org/10. 1016/j.jclepro. 2023. 139941

22. Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G. H., Hilleary, M. A., Eriksen, M., Possingham, H. P., De Frond, H., Gerber, L. R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., & Rochman, C. M. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science, 369(6510), 1515-1518. https://doi. org/10. 1126/ science. Aba 3656

23. Carpenter, E. J., & Smith, K. L., Jr. (1972b). Plastics on the Sargasso sea surface. Science, 175(4027), 1240-1241. https://doi.org/10.1126/science.175.4027.1240

24. Catarino, A. I., Mahu, E., Severin, M. I., Akpetou, L. K., Annasawmy, P., Asuquo, F. E., Beckman, F., Benomar, M., Malouli, M., Mees, J., Monteiro, I., Ndwiga, J., Neves Silva, P., Nubi, O. A., Sim, Y. K., Sohou, Z., Woo, S. P., Zizah, S., Everaert, G., . . . Seeyave, S. (2023). Addressing data gaps in marine litter distribution: Citizen science observation of plastics in coastal ecosystems by high-school students. Frontiers in Marine Science, 10, 1126895. https://doi.org/10.3389/fmars.2023.1126895

25. Cesarano, C., Aulicino, G., Cerrano, C., Ponti, M., & Puce, S. (2021). Scientific knowledge on marine beach litter: A bibliometric analysis. Marine Pollution Bulletin, 173, 113102. https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.113102

26. Cesarano, C., Aulicino, G., Cerrano, C., Ponti, M., & Puce, S. (2023). Marine beach litter monitoring strategies along Mediterranean coasts. A methodological review. Marine Pollution Bulletin, 186, 114401. https://doi.org/https: //doi.org/10.1016 /j.marpolbul. 2022 . 114401

27. Chalmin, P. (2019). The history of plastics: From the Capitol to the Tarpeian Rock. Field Actions Science Reports, Special Issue 19, 6-11. https://doi.org/10 .4000/ factsreports. 5071

28. Charles, J. P., Cappellari, O., Spence, A. J., Wells, D. J., & Hutchinson, J. R. (2016). Muscle moment arms and sensitivity analysis of a mouse hindlimb musculoskeletal model. J Anat, 229(4), 514-535. https://doi.org/10.1111/joa.12461

29. Chen, Y., Awasthi, A. K., Wei, F., Tan, Q., & Li, J. (2021). Single-use plastics: Production, usage, disposal, and adverse impacts. Sci Total Environ, 752, 141772. https://doi.org/10.1016/j.scitotenv.2020.141772

30. Chia, W. Y., Ying Tang, D. Y., Khoo, K. S., Kay Lup, A. N., & Chew, K. W. (2020). Nature's fight against plastic pollution: Algae for plastic biodegradation and bioplastics production. Environ Sci Ecotechnol,4, 100065. https://doi.org/10.1016/j.ese.2020.100065

31. COBSEA. (2023). Regional Action Plan on Marine Litter in East Asia. Strategic Directions 2023–2027. United Nations Environment Programme.

32. Chitaka, T.Y., Onianwa, P.C., Nel, H.A. (2023). Marine Litter Sources and Distribution Pathways. In: Maes, T., Preston-Whyte, F. (eds) The African Marine Litter Outlook. Springer, Cham. https://doi.org/10.1007/978-3-031-08626-7_2

33. Choosuk, C., Khunnikom, P., Boonsom, T., Khunwishit, S., Ruthirako, P., Nattharom, N., & Thitinanthakorn, J. (2024). Local perspectives on community-driven marine debris management for sustainable tourism in the Andaman Islands, Thailand. Geojournal of Tourism and Geosites, 55(3), 1156–1163. https://doi.org/10.30892/gtg.55316-1288

34. Colton, J. B., Burns, B. R., & Knapp, Frederick D. (1974). Plastic Particles in Surface Waters of the Northwestern Atlantic. Science, 185(4150), 491-497. https://doi.org/doi:10.1126/science.185.4150.491

35. Connors, P. G., & Smith, K. G. (1982). Oceanic plastic particle pollution: Suspected effect on fat deposition in Red Phalaropes. Marine Pollution Bulletin, 13, 18–20.

36. Cordova, M. R., Iskandar, M. R., & Nurhati, I. S. (2022). Seasonal heterogeneity and a link to precipitation in the release of microplastic during COVID-19 outbreak from the Greater Jakarta area to Jakarta Bay, Indonesia. Marine Pollution Bulletin, 182, 113927. https://doi.org/10.1016/j.marpolbul.2022.113927

37. Cornelius, S. H. (1975). Marine turtle mortalities along the Pacific coast of Costa Rica. Copeia, 1975, 186–187.

38. Cottom, J. W., Cook, E., & Velis, C. A. (2024). A local-to-global emissions inventory of macroplastic pollution. Nature, 633(8028), 101-108. https://doi.org/10.1038/s41586-024-07758-6

39. Cózar, A., Echevarría, F., González-Gordillo, J. I., et al. (2014). Plastic debris in the open ocean. Proceedings of the National Academy of Sciences (PNAS),111(28), 10239–10244. https://doi.org/10.1073/pnas.1314705111

40. Crawford, C. B., & Quinn, B. (2016). Microplastics, standardisation and spatial distribution. Microplastic Pollutants, 101-130. https:// doi. Org /10.1016 /B978-0-12-809406-8.00005-0

41. Daniel, D. B., Thomas, S. N., & Thomson, K. T. (2020). Assessment of fishing-related plastic debris along the beaches in Kerala Coast, India. Marine Pollution Bulletin,150, 110696. https://doi.org/https://doi.org/10.1016/j.marpolbul.2019.110696

42. Delavari Heravi, M., Haddadi, M., Karami Nejad, F., Izadi Yazdanabadi, Z., & Haghighat, G. A. (2024). A comparative study of indexes used for litter pollution assessment in urban and public environments. Heliyon, 10(3), e24954. https:// doi.org/ 10.1016/ j.heliyon .2024.e24954

43. Desforges, J.-P. W., Galbraith, M., Dangerfield, N., & Ross, P. S. (2014). Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. Marine Pollution Bulletin, 79(1), 94-99. https://doi.org /https://doi.org /10.1016/j. marpolbul.2013.12.035

44. Deville, A., Vazquez-Rowe, I., Ita-Nagy, D., & Kahhat, R. (2023). Ocean-based sources of plastic pollution: An overview of the main marine activities in the Peruvian EEZ. Marine Pollution Bulletin,189, 114785. https://doi.org/ https://doi.org/ 10.1016/j.marpolbul.2023.114785

45. Dijkstra, H., van Beukering, P., & Brouwer, R. (2022). Marine plastic entrepreneurship; Exploring drivers, barriers and value creation in the blue economy. Sustainable Technology and Entrepreneurship, 1(3), 100018. https://doi. org/https://doi.org/10.1016/j.stae .2022.100018

46. Dimassi, S. N., Hahladakis, J. N., Daly Yahia, M. N., Ahmad, M. I., Sayadi, S., & Al-Ghouti, M. A. (2023). Insights into the degradation mechanism of PET and PP under marine conditions using FTIR. Journal of Hazardous Materials, 447, 130796. https://doi.org /10.1016/j.jhazmat. 2023.130796

47. Dixon, T. R., & Cooke, A. J. (1977). Discarded containers on a Kent Beach. Marine Pollution Bulletin, 8, 105–109.

48. Do, H., & Armstrong, C. W. (2023). Ghost fishing gear and their effect on ecosystem

services – Identification and knowledge gaps. Marine Policy, 150, 105528. https://doi.org/10.1016/j. marpol. 2023.105528

49. Dowarah, K., & Devipriya, S. P. (2019). Microplastic prevalence in the beaches of Puducherry, India and its correlation with fishing and tourism/recreational activities. Marine Pollution Bulletin, 148, 123-133. https://doi.org/https:// doi.org/10.1016/j. marpolbul.2019. 07.066

50. Duncan, E. M., Botterell, Z. L. R., Broderick, A. C., Galloway, T. S., Lindeque, P. K., Nuno, A., & Godley, B. J. (2017). A global review of marine turtle entanglement in anthropogenic debris: a baseline for further action. Endangered Species Research, 34, 431-448. https://www.int-res.com/abstracts/esr/v34/p431-448/

51. Edyvane, K. S., Dalgetty, A., Hone, P. W., Higham, J. S., & Wace, N. M. (2004). Long-term marine litter monitoring in the remote Great Australian Bight, South Australia. Marine Pollution Bulletin, 48(11), 1060-1075. https://doi.org/ https://doi.org /10.1016/j. marpolbul. 2003. 12.012

52. Efron, B., & Tibshirani, R. J. (1994).An introduction to the bootstrap. Chapman & Hall/CRC.

53. Elhacham, E., Ben-Uri, L., Grozovski, J., Bar-On, Y.M., and Milo, R. 2020. Global human-made mass exceeds all living biomass. Nature, 588(7838): 442–444. doi:10.1038/s41586-020-3010-5. PMID: 33299177.

54. Environmental Protection Agency. (2021). The Rapids: US EPA's Trash Free Waters Monthly Update - June 2021. U.S. Environmental Protection Agency. https://www.epa. gov/ system /files /documents/2021-09/rapids-june-2021.pdf

55. Eo, S., Hong, S. H., Song, Y. K., Han, G. M., Seo, S., Park, Y.-G., & Shim, W. J. (2022). Underwater hidden microplastic hotspots: Historical ocean dumping sites. Water Research, 216, 118254. https://doi.org/https://doi.org/10.1016/j.watres.2022.118254

56. Ertaş, A. (2021). Assessment of origin and abundance of beach litter in Homa Lagoon coast, West Mediterranean Sea of Turkey. Estuarine, Coastal and Shelf Science, 249, 107114. https://doi.org/10.1016/j.ecss.2020.107114

57. European Marine Observation and Data Network, 2023. Beach Litter dataset. Accessed on April 2024. https://emodnet.ec.europa.eu/. https://doi.org/10.6092/kva0-xe59.

58. European Marine Strategy Framework Directive (2008).Directive 2008/56/EC of theEuropean Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal of the European Union, L164, 19-40. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0056

59. European Union. (2022). Circular Economy Action Plan: Plastics and Fishing Gear Strategy.

60. European Commission, 2019: European Commission. (2019). Directive (EU) 2019/904 on the reduction of plastic pollution from single-use products and fishing gear.

61. European Commission (EC). (2008). Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal of the European

Union, L164, 19–40. https://eur-lex.europa.eu/eli/dir/2008/56/oj

62. FAO (2016).International Standard Statistical Classification of Fishing Gear (ISSCFG) – Revision 1. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

63. FAO and UNEP (2009). Food and Agriculture Organization (FAO) & United Nations Environment Programme (UNEP). (2009). Abandoned, lost or otherwise discarded fishing gear. UNEP Regional Seas Reports and Studies No. 185; FAO Fisheries and Aquaculture Technical Paper No. 523. Rome: UNEP/FAO.

64. FAO. (2018). Abandoned, lost and discarded gillnets and trammel nets: Methods to estimate ghost fishing mortality, and the status of regional monitoring and management. FAO Fisheries and Aquaculture Technical Paper No. 633.

65. FAO. (2019). Voluntary Guidelines on the Marking of Fishing Gear. Food and Agriculture Organization of the United Nations.

66. FAO, 2022: Food and Agriculture Organization. (2022). Voluntary Guidelines on the Marking of Fishing Gear and Reduction of ALDFG.

67. FAO-GGGI. (2023). Annual Report of the Global Ghost Gear Initiative.

68. FAO-GGGI. (2022). Food and Agriculture Organization of the United Nations & Global Ghost Gear Initiative. (2022). Report on good practices to prevent and reduce marine plastic litter from fishing activities(FAO/GGGI Information Paper prepared for UNEA 5.2 negotiations). Rome: FAO & GGGI.

69. Farias, E. G. G., Preichardt, P. R., &Dantas, D. V. (2018). Influence of fishing activity over the marine debris composition close to coastal jetty. Environmental Science and Pollution Research, 25(16), 16246-16253. https://doi.org/10.1007/s11356-018-2012-4

70. Fernández García, G., Asensio-Montesinos, F., Anfuso, G., & Arenas-Granados, P. (2024). Beach Litter Variability According to the Number of Visitors in Cádiz Beaches, SW Spain. Journal of Marine Science and Engineering, 12(2), 201. https://doi.org/10.3390/jmse12020201

71. Ford, H. V., Jones, N. H., Davies, A. J., Godley, B. J., Jambeck, J. R., Napper, I. E., Suckling, C. C., Williams, G. J., Woodall, L. C., & Koldewey, H. J. (2022). The fundamental links between climate change and marine plastic pollution. Science of the Total Environment, 806, 150392. https://doi.org/10.1016/j.scitotenv.2021.150392

72. Fred-Ahmadu, O. H., Ahmadu, F. O., Adedapo, A. E., Oghenovo, I., Ogunmodede, O. T., & Benson, N. U. (2024). Microplastics and chemical contamination in aquaculture ecosystems: The role of climate change and implications for food safety-a review. Environmental Sciences Europe, 36(1), 181. https://doi.org/10.1186/s12302-024-00995-6

73. Fruergaard, M., Laursen, S. N., Larsen, M. N., Posth, N. R., Niebe, K. B., Bentzon-Tarp, A., Svenningsen, S. K., Acevedo N., L. I., Trinh, B., Tran-Thi, P. T., Doan-Nhu, H., Nguyen-Ngoc, L., & Andersen, T. J. (2022). Abundance and sources of plastic debris on beaches in a plastic hotspot, NhaTrang, Viet Nam. Marine Pollution Bulletin, 186, 114394. https://doi.org/10.1016/j.marpolbul.2022.114394

74. Fürst, K., & Feng, Y. (2022). China's regulatory respond to plastic pollution: Trends and trajectories. Frontiers in Marine Sci-

ence, 9, 982546. https://doi.org/10.3389/fmars.2022.982546

75. Gaibor, N., Condo-Espinel, V., Cornejo-Rodríguez, M. H., Darquea, J. J., Pernia, B., Domínguez, G. A., Briz, M. E., Márquez, L., Laaz, E., Alemán-Dyer, C., Avendaño, U., Guerrero, J., Preciado, M., Honorato-Zimmer, D., &Thiel, M. (2020). Composition, abundance and sources of anthropogenic marine debris on the beaches from Ecuador – A volunteer-supported study. Marine Pollution Bulletin, 154, 111068. https://doi.org/10.1016/j.marpolbul.2020.111068

76. Galgani, F., Hanke, G., Werner, S., & De Vrees, L. (2015). Global distribution, composition and abundance of marine litter. In M. Bergmann, L. Gutow, & M. Klages (Eds.), Marine anthropogenic litter (pp. 29–56). Springer. https://doi.org/10.1007/978-3-319-16510-3_2

77. Gallagher, A., Randall, P., Sivyer, D., Binetti, U., Lokuge, G., & Munas, M. (2023). Abandoned, lost or otherwise discarded fishing gear (ALDFG) in Sri Lanka – A pilot study collecting baseline data. Marine Policy, 148, 105386. https://doi.org/https://doi.org/10.1016/j.marpol.2022.105386

78. García Rellán, A., Vázquez Ares, D., Vázquez Brea, C., Francisco López, A., & Bello Bugallo, P. M. (2023). Sources, sinks and transformations of plastics in our oceans: Review, management strategies and modelling. Sci Total Environ, 854, 158745. https://doi.org/10.1016/j.scitotenv.2022.158745

79. Garcia-Vazquez, E., & Garcia-Ael, C. (2021). The invisible enemy. Public knowledge of microplastics is needed to face the current microplastics crisis. Sustainable Production and Consumption, 28, 1076-1089. https://doi.org/https://doi.org /10.1016/j.spc.2021. 07.032

80. Garrard, S. L., Clark, J. R., Martin, N., Nelms, S. E., Botterell, Z. L. R., Cole, M., Coppock, R. L., Galloway, T. S., Green, D. S., Jones, M., Lindeque, P. K., Tillin, H. M., & Beaumont, N. J. (2024). Identifying potential high-risk zones for land-derived plastic litter to marine megafauna and key habitats within the North Atlantic. Science of the Total Environment, 922, 171282. https://doi.org/10.1016/j.scitotenv.2024.171282

81. GESAMP (2019). Guidelines for the monitoring and assessment of plastic litter and microplastics in the ocean (Kershaw, P.J., Turra, A., & Galgani, F., Eds.). GESAMP Reports and Studies No. 99.

82. GESAMP, 2016: Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. (2016). Sources, Fate and Effects of Microplastics: Part Two.

83. GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) 2019. Guidelines for the monitoring and assessment of plastic litter and microplastics in the ocean (Kershaw, P.J., Turra, A. and Galgani, F., eds.). (IMO/FAO/UNESCO IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 99, 130 pp.

84. Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7), e1700782. https://doi.org/10.1126/sciadv.1700782

85. Gilman, E., Chopin, F., Suuronen, P., Kuemlangan, B. (2016). Abandoned, lost and discarded gillnets and trammel nets: Methods to estimate ghost fishing mortality, and status of regional monitoring and management. FAO Fisheries and Aqua-

culture Technical Paper No. 600. Food and Agriculture Organization of the United Nations.

86. Greenwaves/WWF India (2021–2022). Ghost net upcycling model in coastal Andhra Pradesh. Reported in The Hindu and Mongabay India.

87. Gunasekaran, K., Mghili, B., Bottari, T., Mancuso, M., & Machendiranathan, M. (2024). Ghost fishing gear threatening aquatic biodiversity in India. Biological Conservation, 291, 110514. https://doi.org/10.1016/j.biocon.2024.110514

88. Global Ghost Gear Initiative. (2023). Community reporting and ALDFG recovery projects. Retrieved from https://www.ghostgear.org/projects

89. Han, Q., Qiu, C., Zeng, W., Chen, S., Zhao, M., Shi, Y., & Zhang, X. (2023). Sediment Carbon Sequestration and Driving Factors in Seagrass Beds from Hainan Island and the Xisha Islands. Processes, 11(2), 456. https://doi.org/10.3390/pr11020456

90. Hardesty, B. D., Good, T. P., & Wilcox, C. (2015). Novel methods, new results and science-based solutions to tackle marine debris impacts on wildlife. Ocean & Coastal Management, 115, 4-9. https://doi.org/10.1016/j.ocecoaman.2015.04.004

91. Hardesty, B. D., Roman, L., Duke, N. C., Mackenzie, J. R., & Wilcox, C. (2021). Abandoned, lost and discarded fishing gear 'ghost nets' are increasing through time in Northern Australia. Marine Pollution Bulletin, 173, 112959. https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.112959

92. Harikrishnan, T., Janardhanam, M., Sivakumar, P., Sivakumar, R., Rajamanickam, K., Raman, T., Thangavelu, M., Muthusamy, G., & Singaram, G. (2023). Microplastic contamination in commercial fish species in southern coastal region of India. Chemosphere, 313, 137486. https://doi.org/https://doi.org /10.1016 /j. chemosphere .2022. 137486

93. Harrison, L. C., Graham, J. A., Chowdhury, P., Silva, T. A. M., Hoehn, D. P., Samanta, A., Chakraborty, K., Joseph, S., Nair, T. M. B., & Kumar, T. S. (2024). Monsoonal influence on floating marine litter pathways in the Bay of Bengal. EGUsphere, 2024, 1-22. https://doi.org/10.5194/egusphere-2024-3096

94. Haseler, M., Balciunas, A., Hauk, R., Sabaliauskaite, V., Chubarenko, I., Ershova, A., & Schernewski, G. (2020). Marine litter pollution in Baltic Sea beaches – Application of the sand rake method. Frontiers in Environmental Science, 8, 599978. https://doi.org /10.3389 /fenvs. 2020.599978

95. Haseler, M., Ben Abdallah, L., El Fels, L., El Hayany, B., Hassan, G., Escobar-Sánchez, G., Robbe, E., von Thenen, M., Loukili, A., Abd El-Raouf, M., Mhiri, F., El-Bary, A. A., Schernewski, G., & Nassour, A. (2025). Assessment of beach litter pollution in Egypt, Tunisia, and Morocco: a study of macro and meso-litter on Mediterranean beaches. Environmental Monitoring and Assessment, 197(1), 123. https://doi.org /10.1007/s 10661- 024- 13517-x

96. Havas, V., Cantillo, J., & Deshpande, P. C. (2024). Comparing the end-of-life circularity potential of commercial fishing gear deployed in Norway by applying multi-criteria decision analysis (MCDA). Marine Pollution Bulletin, 209, 117066. https://doi.org /10.1016/j. marpolbul. 2024.117066

97. He, P., Chopin, F., Suuronen, P., Ferro, R. S. T., & Lansley, J. (2021). Classification and illustrated definition of fishing gears. FAO Fisheries and Aquaculture Technical Paper No. 672. Food and Agriculture Organiza-

tion of the United Nations. https://doi.org/10.4060/cb4966en

98. Honorato-Zimmer, D., Kruse, K., Knickmeier, K., Weinmann, A., Hinojosa, I. A., & Thiel, M. (2019). Inter-hemispherical shoreline surveys of anthropogenic marine debris – A binational citizen science project with schoolchildren. Marine Pollution Bulletin, 138, 464-473. https://doi.org/https://doi.org/10.1016/j.marpolbul.2018.11.048

99. Horpet, P., Jaroensutasinee, M., & Jaroensutasinee, K. (2020). Impacts of tourism on marine debris and microplastic detection at Samui Island, Southern Thailand. INNODOCT/20. International Conference on Innovation, Documentation and Education, 145–153. https://doi.org/10.4995/INN2020.2020.11870

100. Hossain, R., Islam, M. T., Shanker, R., Khan, D., Locock, K. E. S., Ghose, A., Schandl, H., Dhodapkar, R., & Sahajwalla, V. (2022). Plastic Waste Management in India: Challenges, Opportunities, and Roadmap for Circular Economy. Sustainability, 14(8), 4425. https://doi.org/10.3390/su14084425

101. ICZM, 2022: Ministry of Environment, Forest and Climate Change. (2022). Integrated Coastal Zone Management (ICZM) Phase II Proposal.

102. Iglesias, I., Lupiac, M., Vieira, L., Antunes, S., Mira-Veiga, J., Sousa-Pinto, I., & Lobo, A. (2023). Socio-economic factors affecting the distribution of marine litter: The Portuguese case study. Marine Pollution Bulletin, 193, 115168. https://doi.org/10.1016/j.marpolbul.2023.115168

103. Iheanacho, S., Ogbu, M., Bhuyan, M. S., & Ogunji, J. (2023). Microplastic pollution: An emerging contaminant in aquaculture. Aquaculture and Fisheries, 8(6), 603-616. https://doi.org/https://doi.org/10.1016/j.aaf.2023.01.007

104. Ilechukwu, I., Das, R. R., Jamodiong, E. A., Borghi, S., Manzano, G. G., Hakim, A. A., & Reimer, J. D. (2024). Abundance and distribution of marine litter on the beaches of Okinawa Island, Japan. Marine Pollution Bulletin, 200, 116036. https://doi.org/10.1016/j. marpolbul. 2024.116036

105. INOPOL. (2022). Norwegian Institute for Water Research. (2022). Plastic Waste Management Strategy Report for Gujarat.https://www.niva.no/prosjekter/inopol/fase-1/_/attachment/inline/c31c8d0e-d9cc-42b4-af3e-ecb1fe83b89 5%3A635a 4b5 a40 3d6 fb230a5d0a9f814401b76b47ae3/PWM%20Report.pdf

106. International Maritime Organization. (2018).Action Plan to Address Marine Plastic Litter from Ships (Resolution MEPC.310 (73), adopted 26 October 2018). Marine Environment Protection Committee, 73rd session. Retrieved from IMO archives

107. Ivar do Sul, J. A., Spengler, Â.,& Costa, M. F. (2009). Here, there and everywhere. Small plastic fragments and pellets on beaches of Fernando de Noronha (Equatorial Western Atlantic). Marine Pollution Bulletin, 58(8), 1236–1238. https://doi.org/10.1016/j.marpolbul.2009.05.004

108. Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Marine pollution. Plastic waste inputs from land into the ocean. Science, 347(6223), 768-771. https://doi.org/10.1126/science.1260352

109. Jamieson, A. J., Brooks, L. S. R., Reid, W. D. K., Piertney, S. B., Narayanaswamy, B. E., & Linley, T. D. (2019). Microplastics and synthetic particles ingested by deep-sea

amphipods in six of the deepest marine ecosystems on Earth. R Soc Open Sci, 6(2), 180667. https://doi.org/10.1098/rsos.180667

110. Jayasiri, H. B., Purushothaman, C. S., & Vennila, A. (2013). Quantitative analysis of plastic debris on recreational beaches in Mumbai, India. Mar Pollut Bull, 77(1-2), 107-112. https://doi.org/10.1016/j.marpolbul.2013.10.024

111. Jayavel, S., Govindaraju, B., Michael, J. R., & Viswanathan, B. (2024). Impacts of micro and nanoplastics on human health. Bulletin of the National Research Centre, 48(1), 110. https://doi.org/10.1186/s42269-024-01268-1

112. Jeong, E., Lee, J., & Redwan, M. (2024). Animal exposure to microplastics and health effects: A review. Emerging Contaminants, 10(4), 100369. https://doi.org/10.1016/j.emcon.2024.100369

113. Jeyasanta, K. I., Sathish, N., Patterson, J., & Edward, J. K. P. (2020). Macro-, meso- and microplastic debris in the beaches of Tuticorin district, Southeast coast of India. Marine Pollution Bulletin, 154, 111055. https://doi.org/https:/ /doi.org/ 10.1016/ j.marpolbul. 2020.111055

114. Jonidi Jafari, A., Latifi, P., Kazemi, Z., Kazemi, Z., Morovati, M., Farzadkia, M., & Torkashvand, J. (2021). Development a new index for littered waste assessment in different environments: A study on coastal and urban areas of northern Iran (Caspian Sea). Marine Pollution Bulletin, 171, 112684. https:// doi.org/10.1016/j. marpolbul. 2021. 112684

115. Kaladharan, P., Vijayakumaran, K., Singh, V. V., Prema, D., Asha, P. S., Sulochanan, B., Hemasankari, P., Edward, L. L., Padua, S., Veena, S., Anasukoya, A., & Bhint, H. M. (2017). Prevalence of marine litter along the Indian beaches: A preliminary account on its status and composition. Journal of the Marine Biological Association of India, 59(1), 19–24. https://doi.org/10.6024/jmbai.2017.59.1.1953-03

116. Kannan, G., Mghili, B., Di Martino, E., Sanchez-Vidal, A., & Figuerola, B. (2023). Increasing risk of invasions by organisms on marine debris in the Southeast coast of India. Marine Pollution Bulletin, 195, 115469. https://doi.org/https://doi.org/10.1016 /j.marpolbul. 2023.115469

117. Karthikeyan, P., & Subagunasekar, M. (2023). Microplastics pollution studies in India: A recent review of sources, abundances and research perspectives. Regional Studies in Marine Science, 61, 102863. https://doi.org/https://doi.org/ 10.1016/j.rsma. 2023. 102863

118. Kasa, V. P., Brahmandam, A. K. S., Samal, B., Cheela, V. R. S., Dubey, B. K., & Pathak, K. (2025). Assessment of coastal litter trends in tourist vs. Non-tourist beaches: A case study from Indian coastal smart city. Science of The Total Environment, 959, 178339. https://doi.org/10.1016/j.scitotenv.2024.178339

119. Kaviarasan, T., Dhineka, K., Sambandam, M., Sivadas, S. K., Sivyer, D., Hoehn, D., Pradhan, U., Mishra, P., & RamanaMurthy, M. V. (2022). Impact of multiple beach activities on litter and microplastic composition, distribution, and characterization along the southeast coast of India. Ocean & Coastal Management, 223, 106177. https://doi.org/https://doi.org/10.1016/j.ocecoaman.2022.106177

120. Kaviarasan, T., Naik, S., Sivadas, S. K., Dhineka, K., Sambandam, M., Sivyer, D., Mishra, P., & Ramana Murthy, M. V. (2020). Assessment of litter in the remote beaches of Lakshadweep Islands, Arabian Sea. Marine Pollution Bulletin, 161, 111760.

https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.111760

121. Keerthika, K., Padmavathy, P., Rani, V., Jeyashakila, R., Aanand, S., & Kutty, R. (2022). Contamination of microplastics, surface morphology and risk assessment in beaches along the Thoothukudi coast, Gulf of Mannar region. Environmental Science and Pollution Research, 29(50), 75525-75538. https://doi.org/10.1007/s11356-022-21054-8

122. Keerthika, K., Padmavathy, P., Rani, V., Jeyashakila, R., Aanand, S., Kutty, R., Tamilselvan, R., & Subash, P. (2023). Microplastics accumulation in pelagic and benthic species along the Thoothukudi coast, South Tamil Nadu, India. Marine Pollution Bulletin,189, 114735. https://doi.org/ https://doi.org /10.1016/j. marpolbul.2023. 114735

123. Kenyon, K. W., & Kridler, E. (1969). Laysan Albatrosses swallow indigestible matter. The Auk, 86(2), 339–343. https://doi.org/10.2307/4083505

124. Khan, A. W. (2024,). Study uncovers alarming plastic pollution on Goa's beaches. The Navhind Times.https://www.navhindtimes.in/2024/10/01/goanews/study-uncovers-alarming-plastic-pollution-on-goas-beaches/

125. Kingsolver, W. (2022). Effects of Plastic and Waste Pollution on Ocean Communities in the Asian Pacific Region. Ballard Brief, 2022(3), Article 14.

126. KIMO International. (2020). Six steps for municipalities to tackle ghost gear. Retrieved from https://www.kimointernational.org/news/six-steps-for-municipalities-to-tackle-ghost-gear

127. Krelling, A. P., Williams, A. T., & Turra, A. (2017). Differences in perception and reaction of tourist groups to beach marine debris that can influence a loss of tourism revenue in coastal areas. Marine Policy, 85, 87–99. https://doi.org/10.1016/j.marpol.2017.08.021

128. Krishnakumar, S., Anbalagan, S., Kasilingam, K., Smrithi, P., Anbazhagi, S., Srinivasalu, S., (2020). Assessment of plastic debris in remote islands of the Andaman and Nicobar Archipelago, India. Marine Pollution Bulletin, 151, 110841.https://doi.org/10.1016/j.marpolbul.2019.110841

129. Krishnakumar, S., Srinivasalu, S., Saravanan, P., Vidyasakar, A., & Magesh, N. S. (2018). A preliminary study on coastal debris in Nallathanni Island, Gulf of Mannar Biosphere Reserve, Southeast coast of India. Marine Pollution Bulletin, 131, 547-551. https://doi.org/https://doi.org/10.1016/j.marpolbul.2018.04.026

130. Krishnan, P., Bilal, M., Perumal, K., Kabalieshwaran, M., Kabalieshwaran, R., Muthuramalingam, S., Kolanthasamy, P., & Chellaiyan, S. (2022).Fishing litter dominates the litter along the beaches of Palk Bay, Southeastern of India.https://doi.org/10.21203/rs.3.rs-2202949/v2

131. Kumar, A.A., Sivakumar, R., Reddy, Y. S. R., M.V., B. R., T., N., & V., R. (2016). Preliminary study on marine debris pollution along Marina beach, Chennai, India. Regional Studies in Marine Science, 5, 35-40. https://doi.org/10.1016/j.rsma.2016.01.002

132. Landrigan, P. J., Stegeman, J. J., Fleming, L. E., Allemand, D., Anderson, D. M., Backer, L. C., Brucker-Davis, F., Chevalier, N., Corra, L., Czerucka, D., Bottein, M. D., Demeneix, B., Depledge, M., Deheyn, D. D., Dorman, C. J., Fénichel, P., Fisher, S., Gaill, F., Galgani, F., . . . Rampal, P. (2020). Human Health and Ocean Pollution. Ann Glob Health, 86(1), 151. https://doi.org/10.5334/aogh.2831

133. Lau, W. W. Y., Shiran, Y., Bailey, R. M., Cook, E., Stuchtey, M. R., Koskella, J., Velis, C. A., Godfrey, L., Boucher, J., Murphy, M. B., Thompson, R. C., Jankowska, E., Castillo Castillo, A., Pilditch, T. D., Dixon, B., Koerselman, L., Kosior, E., Favoino, E., Gutberlet, J., . . . Palardy, J. E. (2020). Evaluating scenarios toward zero plastic pollution. Science, 369(6510), 1455-1461. https://doi.org/doi:10.1126/science.aba9475

134. Law, K. L., Starr, N., Siegler, T. R., Jambeck, J. R., Mallos, N. J., & Leonard, G. H. (2020). The United States' contribution of plastic waste to land and ocean. Science Advances. https://doi.org/abd0288

135. Lebreton, L. C. M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world's oceans. Nature Communications, 8, 15611. https://doi.org/10.1038/ncomms15611

136. Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., Hajbane, S., Cunsolo, S., Schwarz, A., Levivier, A., Noble, K., Debeljak, P., Maral, H., Schoeneich-Argent, R., Brambini, R., & Reisser, J. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Sci Rep, 8(1), 4666. https://doi.org/10.1038/s41598-018-22939-w

137. Lechthaler, S., Waldschläger, K., Sandhani, C. G., Sannasiraj, S. A., Sundar, V., Schwarzbauer, J., & Schüttrumpf, H. (2021). Baseline Study on Microplastics in Indian Rivers under Different Anthropogenic Influences. Water, 13(12), 1648. https://doi.org/10.3390/w13121648

138. Li, P., Karunanidhi, D., Subramani, T., & Srinivasamoorthy, K. (2021). Sources and Consequences of Groundwater Contamination. Arch Environ Contam Toxicol,80(1), 1-10. https://doi.org/10.1007/s00244-020-00805-z

139. Lincoln, S., Andrews, B., Birchenough, S. N., Chowdhury, P., Engelhard, G. H., Harrod, O., Pinnegar, J. K., & Townhill, B. L. (2022). Marine litter and climate change: Inextricably connected threats to the world's oceans. Science of The Total Environment, 837, 155709. https://doi.org/10.1016/j.scitotenv.2022.155709

140. Lincoln, S., Chowdhury, P., Posen, P. E., Robin, R., Ramachandran, P., Ajith, N., Harrod, O., Hoehn, D., Harrod, R., & Townhill, B. L. (2023). Interaction of climate change and marine pollution in Southern India: Implications for coastal zone management practices and policies. Science of The Total Environment, 902, 166061. https://doi. org/10.1016 /j. scitotenv. 2023.166061

141. Link, J., Segal, B., & Casarini, L. M. (2018). Abandoned, lost or otherwise discarded fishing gear in Brazil: A review. Perspectives in Ecology and Conservation, 17(1), 1-8. https://doi.org/10.1016/j.pecon.2018.12.003

142. Lippiatt, S.; Opfer, S. and Arthur, C. (2013). Marine Debris Monitoring and Assessment: Recommendations for Monitoring Debris Trends in the Marine Environment. Silver Spring, MD, NOAA Marine Debris Division, 82pp. (NOAA Technical Memorandum NOS-OR&R-46). DOI: http://dx.doi.org/10.25607/OBP-727

143. Liu, S., Shi, J., Wang, J., Dai, Y., Li, H., Li, J., Liu, X., Chen, X., Wang, Z., & Zhang, P. (2021). Interactions between microplastics and heavy metals in aquatic environments: A Review. Front Microbiol, 12, 652520. https://doi.org/10.3389/fmicb.2021.652520

144. Löhr, A., Savelli, H., Beunen, R., Kalz, M., Ragas, A., & Van Belleghem, F. (2017). Solutions for global marine litter pollution. Current Opinion in Environmental

Sustainability, 28, 90–99. https://doi.org/10.1016/j.cosust.2017.08.009

145. Macfadyen, G., Huntington, T., & Cappell, R. (2009). Abandoned, lost or otherwise discarded fishing gear. UNEP Regional Seas Reports and Studies No. 185; FAO Fisheries and Aquaculture Technical Paper No. 523. United Nations Environment Programme & Food and Agriculture Organization of the United Nations.

146. Mahadevia, D. (1999). Economic Growth and Environmental Degradation: Case of Gujarat. Research Foundation for Science, Technology and Ecology, New Delhi.

147. Mantelatto, M. C., Póvoa, A. A., Skinner, L. F., Araujo, F. V. D., & Creed, J. C. (2020). Marine litter and wood debris as habitat and vector for the range expansion of invasive corals (*Tubastraea* spp.). Marine Pollution Bulletin, 160, 111659. https://doi. org/10.1016 /j. marpolbul.2020.111659

148. MARESSOL, 2022. Marine Litter from Fisheries in the Gulf of Mannar and Palk Strait: Knowledge Basis and Recommended Avenues for Change. Authors: Carl Höjman, Marthe Larsen Haarr, RuiPires, Guri-HjallenEriksen, Helene SkjeieThorstensen, Edward J.K. Patterson, ArjanRajasuriya, DinithiSamarathunga, Immaculate K. Jeyasanta, Laju R. L., Jamila Patterson, Terney Pradeep Kumara, YohanMahagamage, AnandaMallawatantri, ShamenVidanage, Brita Staal. Technical Report, https://salt.nu/assets/projects/MARESSOL-PROJECT-REPORT--SUMMARY-eversion.pdf

149. Marin, C. B., Niero, H., Zinnke, I., Pellizzetti, M. A., Santos, P. H., Rudolf, A. C., Beltrão, M., Waltrick, D. d. S., & Polette, M. (2019). Marine debris and pollution indexes on the beaches of Santa Catarina State, Brazil. Regional Studies in Marine Science, 31, 100771. https://doi.org/https://doi.org/10.1016/j.rsma.2019.100771

150. Martín-Lara, M. A., Godoy, V., Quesada, L., Lozano, E. J., & Calero, M. (2021). Environmental status of marine plastic pollution in Spain. Marine Pollution Bulletin, 112677. https://doi.org/10.1016/j.marpolbul.2021.112677

151. McIntyre, J., Duncan, K., Fulton, L., Smith, A., Goodman, A. J., Brown, C. J., & Walker, T. R. (2023). Environmental and economic impacts of retrieved abandoned, lost, and discarded fishing gear in Southwest Nova Scotia, Canada. Marine Pollution Bulletin, 192, 115013. https://doi.org/10.1016/j.marpolbul.2023.115013

152. Meijer, L. J. J., van Emmerik, T., van der Ent, R., Schmidt, C., & Lebreton, L. (2021). More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Sci Adv, 7(18). https://doi.org/10.1126/sciadv.aaz5803

153. Mengo, E., Randall, P., Larsonneur, S., Burton, A., Hegron, L., Grilli, G., Russell, J., & Bakir, A. (2023). Fishers' views and experiences on abandoned, lost or otherwise discarded fishing gear and end-of-life gear in England and France. Marine Pollution Bulletin, 194, 115372. https://doi.org/10.1016/j.marpolbul.2023.115372

154. Miyake, H., Shibata, H. & Furushima, Y. (2011). Deep-Sea Litter Study Using Deep-Sea Observation Tools. In: Omori, K., Guo, X., Yoshie, N., Fujii, N., Handoh, I. C., Isobe, A. & Tanabe, S. Interdisciplinary Studies on Environmental Chemistry - Marine Environmental Modeling & Analysis (pp. 261-269). Japan: Terrapub.

155. Mghili, B., Hasni, S., Ben-Haddad, M., Rangel-Buitrago, N., Keznine, M., Lamine, I., Hamiche, F. Z., Haddaoui, H., Abelouah, M. R., Demiathi, M., Oubahaouali, B., Jellal,

N., Touaf, M., Ahannach, Y., Hassou, N., Cherradi, S., & Aksissou, M. (2024). Plastic pollution on Moroccan beaches: Toward baselines for large-scale assessment. Marine Pollution Bulletin, 201, 116288. https://doi.org/10.1016/j.marpolbul.2024.116288

156. Mghili, B., Lamine, I., Bouzekry, A., Gunasekaran, K., & Aksissou, M. (2023). Cigarette butt pollution in popular beaches of Morocco: Abundance, distribution, and mitigation measures. Marine Pollution Bulletin, 195, 115530. https://doi. org/10.1016/j. marpolbul. 2023.115530

157. Mishra, A. K., Singh, J., & Mishra, P. P. (2021). Microplastics in Polar Regions: An early warning to the world's pristine ecosystem. Science of The Total Environment, 784, 147149. https://doi.org/10.1016/j. scitotenv.2021.147149

158. Mishra, A., Siht, E., Väli, G., Liblik, T., Buhhalko, N., & Lips, U. (2025). Mapping microplastic pathways and accumulation zones in the Gulf of Finland, Baltic Sea – insights from modeling. Frontiers in Marine Science, 11, 1524585. https://doi. org/ 10.3389 / fmars.2024.1524585

159. Mishra, P., Kaviarasan, T., Sambandam, M., Dhineka, K., Murthy, M. V. R., Iyengar, G., Singh, J., & Ravichandran, M. (2023). Assessment of national beach litter composition, sources, and management along the Indian coast - a citizen science approach. Marine Pollution Bulletin, 186, 114405. https://doi.org/https://doi.org/10.1016/j. marpolbul.2022.114405

160. Mishra, P., Kaviarasan, T., Sambandam, M., Dhineka, K., Murthy, M. R., Iyengar, G., Singh, J., & Ravichandran, M. (2022). Assessment of national beach litter composition, sources, and management along the Indian coast - a citizen science approach. Marine Pollution Bulletin, 186, 114405. https://doi.org/10.1016/j.marpolbul.2022.114405

161. Ministry of Ports, Shipping and Waterways. (2025, April 29). Revised length of India's coastline [Government circular]. Government of India. https://shipmin.gov. in/sites/default/files/Length%20of%20 Indias%20Coastline%20Circular.pdf

162. Ministry of Earth Sciences. (2025, June 5). India steps up for cleaner oceans! The Draft National Marine Litter Policy was unveiled at ClimateNXT 2025. LinkedIn. Retrieved from MoES official LinkedIn page.

163. Ministry of Housing and Urban Affairs (MoHUA). (2022). Swachh Bharat Mission – Urban 2.0 Guidelines. Retrieved from https://static.pib.gov.in/WriteReadData/specificdocs/documents/2022/jul/doc20227169001.pdf

164. MoEFCC (2018). Draft National Marine Litter Policy https://moef.gov.in/uploads/2019/10/Beat-Plastic-Pollution.pdf

165. MoEFCC, 2020: Ministry of Environment, Forest and Climate Change. (2020). National Biodiversity Action Plan.

166. Ministry of Environment, Forest and Climate Change (MoEFCC). (2022). Plastic Waste Management (Amendment) Rules, 2022. Retrieved from https://www.moes.gov.in/sites/default/files/PIB1838823.pdf

167. MoEFCC (2021). Vision Document for a Plastic Waste-Free Coastal India https://moef.gov.in/uploads/2023/05/Annual-Report-English-2023-24.pdf

168. MoEFCC. (2024). EPR Guidelines for Plastic Packaging under Plastic Waste Management Rules. Ministry of Environment, Forest and Climate Change, Government of India.

169. MoES (2024). (MoES Reply to Rajya Sabha, 2024): https:// moes.gov.in/sites/default / files/RS-English-662-08-02-2024.pdf

170. Ministry of Earth Sciences (MoES). (2024). Swachh Sagar, Surakshit Sagar Campaign promotes community-led ocean clean-up. Retrieved from https://www.pib.gov.in/PressReleasePage.aspx?PRID=2057467

171. Moore, C. J., Moore, S. L., Leecaster, M. K., & Weisberg, S. B. (2001). A comparison of plastic and plankton in the North Pacific central gyre. Marine Pollution Bulletin, 42(12), 1297–1300. https://doi.org/10.1016/S0025-326X(01)00114-X

172. Mongabay India, (2025). Creating a blue-print for cleaner oceans. Retrieved from https://india.mongabay.com/2025/02/creating-a-blueprint-for-cleaner-oceans/

173. Moshood, T. D., Nawanir, G., Mahmud, F., Mohamad, F., & Ahmad, M. H. (2021). Expanding policy for biodegradable plastic products and market dynamics of bio-based plastics: Challenges and opportunities. Sustainability, 13(11), 6150. https://doi.org/10.3390/su13116150

174. Moyal, J., Dave, P. H., Wu, M., Karimpour, S., Brar, S. K., Zhong, H., & Kwong, R. W. M. (2023). Impacts of Biofilm Formation on the Physicochemical Properties and Toxicity of Microplastics: A Concise Review. Reviews of Environmental Contamination and Toxicology, 261(1), 8. https://doi.org/10.1007/s44169-023-00035-z

175. Mrozik, W., Rajaeifar, M. A., Heidrich, O., & Christensen, P. (2021). Environmental impacts, pollution sources and pathways of spent lithium-ion batteries [10.1039/D1EE00691F]. Energy & Environmental Science, 14(12), 6099-6121. https://doi.org/10.1039/D1EE00691F

176. Mugilarasan, M., Karthik, R., Purvaja, R., Robin, R. S., Subbareddy, B., Hariharan, G., Rohan, S., Jinoj, T. P. S., Anandavelu, I., Pugalenthi, P., & Ramesh, R. (2021). Spatiotemporal variations in anthropogenic marine litter pollution along the northeast beaches of India. Environmental Pollution, 280, 116954. https://doi.org/https://doi.org/10.1016/j.envpol.2021.116954

177. Mugilarasan, M., Karthik, R., Robin, R., Subbareddy, B., Hariharan, G., Anandavelu, I., Jinoj, T., Purvaja, R., & Ramesh, R. (2023). Anthropogenic marine litter: An approach to environmental quality for India's southeastern Arabian Sea coast. Science of The Total Environment, 866, 161363. https://doi.org/10.1016/j.scitotenv.2022.161363

178. Munari, C., Scoponi, M., & Mistri, M. (2017). Plastic debris in the Mediterranean Sea: Types, occurrence and distribution along Adriatic shorelines. Waste Management, 67, 385-391. https://doi.org/10.1016/j.wasman.2017.05.020

179. Murray, F., & Cowie, P. R. (2011). Plastic contamination in the decapod crustacean *Nephrops norvegicus* (Linnaeus, 1758). Mar Pollut Bull,62(6), 1207-1217. https://doi.org /10.1016/j.marpolbul.2011.03.032

180. Nachite, D., Maziane, F., Anfuso, G., & Williams, A. T. (2019). Spatial and temporal variations of litter at the Mediterranean beaches of Morocco mainly due to beach users. Ocean & Coastal Management, 179, 104846. https://doi.org /10.1016/j.ocecoaman. 2019.104846

181. Nama, S., Shanmughan, A., Nayak, B. B., Bhushan, S., & Ramteke, K. (2023). Impacts of marine debris on coral reef ecosystem: A review for conservation and ecological monitoring of the coral reef ecosystem. Marine Pollution Bulletin, 189, 114755. https:// doi.org/ 10.1016/j.marpolbul.2023.114755

182. Nammalwar, P. (2021). Plastic pollution in coastal marine environment-a review. Everyman's Science, 54(5), 316-320.

183. National Mission for Clean Ganga. (2021). Annual report 2020-21. Ministry of Jal Shakti, Department of Water Resources, River Development & Ganga Rejuvenation. https:// nmcg.nic.in/writereaddata/fileupload/19_NMCG%20Annual%20Report%20 2020-21English.pdf

184. Ng, P. S., Maqueda, M. M., & Goh, K. L. (2023). Modelling the transportation of marine plastics over the ocean surface by Cellular Automata. Marine Pollution Bulletin, 191, 114950. https://doi.org/10.1016/j.marpolbul.2023.114950

185. Nguyen, L., & Brouwer, R. (2022). Fishing for Litter: Creating an Economic market for marine plastics in a Sustainable Fisheries Model. Frontiers in Marine Science, 9. https://doi.org/10.3389/fmars.2022.722815

186. National Oceanic and Atmospheric Administration (NOAA). (2020). Marine debris shoreline survey field guide (Version 4.0). U.S. Department of Commerce. https://repository.library.noaa.gov/view/noaa/17535

187. Ochoa-esteso, C., Roselló-carrió, A., Carrasco-correa, E. J., & Lerma-García, M. J. (2024). Bioaccumulation of environmental pollutants and marine toxins in bivalve molluscs: a review. Exploration of Foods and Foodomics, 2(6), 788-809. https:// doi.org /10.37349/ eff. 2024.00062

188. Ocean Conservancy. (2020). Stemming the tide: Land-based strategies for a plastic-free ocean. Retrieved from https://oceanconservancy.org

189. Özşeker, K., Coşkun, T., & Erüz, C. (2024). Exploring seasonal, spatial and pathways of marine litter pollution along the South-eastern Black Sea Cost of Türkiye. Marine Pollution Bulletin, 202, 116348. https:// doi.org/https:// doi.org/10.1016/j. marpolbul.2024. 116348

190. Paler, M. K. O., Malenab, M. C. T., Maralit, J. R., & Nacorda, H. M. (2019). Plastic waste occurrence on a beach off southwestern Luzon, Philippines. Marine Pollution Bulletin, 141, 416-419. https://doi.org/10.1016/j.marpolbul.2019.02.006

191. Parga Martínez, K. B., Tekman, M. B., & Bergmann, M. (2020). Temporal Trends in Marine Litter at Three Stations of the HAUSGARTEN Observatory in the Arctic Deep Sea.Frontiers in Marine Science, 7. https://doi.org/10.3389/fmars.2020.00321

192. Parslow, J., & Jefferies, D. (1972). Elastic thread pollution of puffins. Marine Pollution Bulletin, 3(3), 43-45. https://doi.org/10.1016/0025-326X(72)90142-7

193. Patra, S., Khurshid, M., Basir, A., Mishra, P., & Ramanamurthy, M. V. (2023). Marine litter management: A sustainable action plan and recommendations for the South Asian Seas region. Marine Policy, 157, 105854. https://doi.org/https:// doi.org/10.1016/j.marpol.2023. 105854

194. Patterson, J., Jeyasanta, K. I., Sathish, N., Booth, A. M., & Edward, J. P. (2019). Profiling microplastics in the Indian edible oyster, *Magallana bilineata* collected from the Tuticorin coast, Gulf of Mannar, Southeastern India. Science of The Total Environment, 691, 727-735.

195. Patterson Edward, J. K., Mathews, G., Raj, K. D., Laju, R. L., Bharath, M. S., Kumar, P. D., Arasamuthu, A., & Grimsditch, G. (2020). Marine debris - An emerging threat to the reef areas of Gulf of Mannar, India. Marine Pollution Bulletin,151, 110793.

https://doi.org/https://doi.org/10.1016/j.marpolbul.2019.110793

196. Patterson Edward, J. K., Jayanthi, M., Einarsson, H. A., Kannan, R., Laju, R. L., Jeyasanta, K. I., Sathish, N., & Patterson, J. (2025). Assessment of beach litter, including Abandoned, Lost, or Discarded Fishing Gear (ALDFG), along the coast of Tamil Nadu, India: Magnitude, sources, composition, pollution status, and management strategies. Marine Pollution Bulletin,213, 117700. https://doi.org/https://doi.org/10.

197. Pattiaratchi, C., van der Mheen, M., Schlundt, C., Narayanaswamy, B. E., Sura, A., Hajbane, S., White, R., Kumar, N., Fernandes, M., and Wijeratne, S.: Plastics in the Indian Ocean - sources, transport, distribution, and impacts, Ocean Sci., 18, 1–28, https://doi.org/10.5194/os-18-1-2022, 2022.

198. Pedrotti, M. L., Lombard, F., Baudena, A., Galgani, F., Elineau, A., Petit, S., Henry, M., Troublé, R., Reverdin, G., Ser-Giacomi, E., Kedzierski, M., Boss, E., & Gorsky, G. (2022). An integrative assessment of the plastic debris load in the Mediterranean Sea. Science of The Total Environment, 838, 155958. https://doi.org/10.1016/j.scitotenv.2022.155958

199. Perumal, K., Boopathi, V., Chellaiyan, S. et al. Sources, spatial distribution, and abundance of marine debris on Thondi coast, Palk Bay, Southeast coast of India. Environ Sci Eur 33, 136 (2021). https://doi.org/10.1186/s12302-021-00576-x

200. Perumal, K., Muthuramalingam, S., & Chellaiyan, S. (2022). Marine litter on the beaches of the Kanyakumari, Southern India: An assessment of their abundance and pollution indices. Marine Pollution Bulletin, 186, 114443. https:// doi.org/10.1016/j. marpolbul.2022. 114443

201. Picuno, C., Van Eygen, E., Brouwer, M. T., Kuchta, K., & Thoden van Velzen, E. U. (2021). Factors Shaping the Recycling Systems for Plastic Packaging Waste-A Comparison between Austria, Germany and The Netherlands. Sustainability, 13(12), 6772. https://doi.org/10.3390/su13126772

202. Pilapitiya, P. G. C. N. T., & Ratnayake, A. S. (2024). The world of plastic waste: A review. Cleaner Materials, 11, 100220. https://doi.org/10.1016/j.clema.2024.100220

203. Ponmani, M., Padmavathy, P., Manimekalai, D., Shalini, R., Ravikumar, T., Hariharan, G., & Manickavasagam, S. (2024). Vulnerability of mangrove ecosystems to anthropogenic marine litter along the southeast coast of India. Science of The Total Environment, 956, 177224. https://doi.org/10.1016/j.scitotenv.2024.177224

204. Pradhan, U., Naik, S., Begum, M., Kumar, S. S., Panda, U. S., Mishra, P., & Murthy, M. V. R. (2018). Marine litter: Post-flood nuisance for Chennai beaches. Current Science, 115(8), 1454–1455.

205. Prevenios, M., Zeri, C., Tsangaris, C., Liubartseva, S., Fakiris, E., & Patsialis, T. (2017). Beach litter dynamics on Mediterranean coasts: Distinguishing sources and pathways. Marine Pollution Bulletin, 129(2), 448–457. https://doi.org/10.1016/j.marpolbul .2017. 10.013

206. Press Information Bureau (PIB). (2022, October 12). India now has 12 Blue Flag certified beaches under BEAMS programme. Retrieved from https://www.pib.gov.in/PressReleasePage.aspx?PRID=1843393

207. Primost, M., Chierichetti, M., Castaños, C., Bigatti, G., & Miglioranza, K. (2024). Persistent Organic Pollutants (POPs), Current Use Pesticides (CUPs) and Polycyclic Aromatic Hydrocarbons (PAHs) in edible

marine invertebrates from a Patagonian harbor. Marine Pollution Bulletin, 207, 116940. https://doi.org/10.1016/j.marpolbul.2024.116940

208. Qaiser, Z., Aqeel, M., Sarfraz, W., Fatima Rizvi, Z., Noman, A., Naeem, S., & Khalid, N. (2023). Microplastics in wastewaters and their potential effects on aquatic and terrestrial biota. Case Studies in Chemical and Environmental Engineering, 8, 100536. https://doi.org/https://doi.org/10.1016/j.cscee.2023.100536

209. Ramasamy, R., Nallendiran, L. & Subramanian, R.B. Microfiber Filters for Laundry: A Systematic Review of Effectiveness and Future Research Directions for Pollution Mitigation. Water Air Soil Pollut. 236, 381 (2025). https://doi.org/10.1007/s11270-025-07970-8

210. Rahmatin, N. M., Soegianto, A., Irawan, B., Payus, C. M., Indriyasari, K. N., Marchellina, A., Mukholladun, W., & Irnidayanti, Y. (2023). The spatial distribution and physico-chemical characteristic of microplastics in the sediment and cockle (Anadara granosa) from the coastal waters of East Java, Indonesia, and the health hazards associated with cockle consumption. Marine Pollution Bulletin, 198, 115906. https:// doi.org/10.1016/j.marpolbul.2023. 115906

211. Ramesh, S., & Nagalakshmi, R. (2023). Impact due to microplastic pollution along aquatic environment in Chennai coastal region, India. European Chemical Bulletin, 12(3), 52–71. https://doi.org/10.31838/ecb/2023.12.3.006

212. Rangel-Buitrago, N., Gracia C., A., Vélez-Mendoza, A., Mantilla-Barbosa, E., Arana, V. A., Trilleras, J., & Arroyo-Olarte, H. (2018). Abundance and distribution of beach litter along the Atlantico Department, Caribbean coast of Colombia. Marine Pollution Bulletin, 136, 435-447. https://doi.org/10.1016/j.marpolbul.2018.09.040

213. Rangel-Buitrago, N., Velez-Mendoza, A., Gracia C., A., & Neal, W. J. (2020). The impact of anthropogenic litter on Colombia's central Caribbean beaches. Marine Pollution Bulletin, 152, 110909. https://doi.org/10.1016/j.marpolbul.2020.110909

214. Rangel-Buitrago, N., Williams, A. T., Neal, W. J., Gracia C, A., & Micallef, A. (2022). Litter in coastal and marine environments. Marine Pollution Bulletin, 177, 113546. https://doi.org/https://doi.org/10.1016/j.marpolbul.2022.113546

215. Râpă, M., Cârstea, E. M., Șăulean, A. A., Popa, C. L., Matei, E., Predescu, A. M., Predescu, C., Donțu, S. I., &Dincă, A. G. (2024). An overview of the current trends in marine plastic litter management for a sustainable development. Recycling, 9(2), 30. https://doi.org/10.3390/recycling9020030

216. Rech, S., Macaya-Caquilpán, V., Pantoja, J. F., Rivadeneira, M. M., Jofre Madariaga, D., & Thiel, M. (2014). Rivers as a source of marine litter--a study from the SE Pacific. Mar Pollut Bull, 82(1-2), 66-75. https://doi.org/10.1016/j.marpolbul.2014.03.019

217. Rech, S., Salmina, S., Borrell Pichs, Y. J., & García-Vazquez, E. (2018). Dispersal of alien invasive species on anthropogenic litter from European mariculture areas. Marine Pollution Bulletin, 131, 10-16. https://doi.org/10.1016/j.marpolbul.2018.03.038

218. Resilient Cities Network. (2024, December 2).Announcing the 2024 Global Risk and Resilience Fellowship Report. https://resilientcitiesnetwork.org/2024/12/announcing-the-2024-global-risk-and-resilience-fellowship-report/

219. Richardson, K., Hardesty, B. D., Wilcox, C., & Gunn, R. (2019). Understanding causes of gear loss provides a sound basis for fisheries management. Fish and Fisheries, 20(3), 428–438. https://doi.org/10.1111/faf.12361

220. Robbe, E., Abdallah, L. B., El Fels, L., Chaher, N. E., Haseler, M., Mhiri, F., &Schernewski, G. (2023). Towards Solving the Beach Litter Problem: Ecosystem Service Assessments at North African Coasts. Sustainability, 16(14), 5911. https://doi.org/10.3390/su16145911

221. Robin, R. S., Karthik, R., Nithin, A., & Purvaja, R. (2023). Removal of marine litter and its impact along the coast of India. Records of the Zoological Survey of India, 123(1S), 67–86. https://doi.org/10.26515/rzsi/v123/i1S/2023/172453

222. Robin, R. S., Purvaja, R., Ganguly, D., Hariharan, G., Paneerselvam, A., Sundari, R. T., Karthik, R., Neethu, C. S., Saravanakumar, C., Semanti, P., Prasad, M. H. K., Mugilarasan, M., Rohan, S., Arumugam, K., Samuel, V. D., & Ramesh, R. (2021). COVID-19 restrictions and their influences on ambient air, surface water and plastic waste in a coastal megacity, Chennai, India. Marine Pollution Bulletin, 171, 112739. https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.112739

223. Rochman, C. M., Hoh, E., Kurobe, T., & Teh, S. J. (2013). Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Scientific Reports, 3(1), 3263. https://doi.org/10.1038/srep03263

224. Rossi, A., Wu, M., Wolde, B. T., Zerbe, K. W., David Hsu, T. T., Giudicelli, A., & Da Silva, R. (2023). Understanding the factors affecting the quantity and composition of street litter: Implication for management practices. *Heliyon*, 9(3), e14245. https://doi.org/10.1016/j.heliyon.2023.e14245

225. Royer, S., Wiggin, K., Kogler, M., & Deheyn, D. D. (2021). Degradation of synthetic and wood-based cellulose fabrics in the marine environment: Comparative assessment of field, aquarium, and bioreactor experiments. Science of The Total Environment, 791, 148060. https://doi.org/10.1016/j.scitotenv.2021.148060

226. Royer, S.-J., Ferrón, S., Wilson, S. T., & Karl, D. M. (2018). Production of methane and ethylene from plastic in the environment. PLOS ONE, 13(8), e0200574. https://doi.org/10.1371/journal.pone.0200574

227. Ruiz, I., Rubio, A., Abascal, A. J., & Basurko, O. C. (2022). Modelling floating riverine litter in the south-eastern Bay of Biscay: a regional distribution from a seasonal perspective. Ocean Science, 18(6), 1703–1724. https:// doi.org/10.5194/os-18-1703-2022

228. Rynek, R., Tekman, M. B., Rummel, C., Bergmann, M., Wagner, S., Jahnke, A., & Reemtsma, T. (2024). Hotspots of floating plastic particles across the North Pacific Ocean. Environmental Science & Technology, 58(9), 4302-4313. https://doi.org/10.1021/ acs.est. 3c05039

229. SACEP. (2019). South Asia Co-operative Environment Programme.,Regional Marine Litter Action Plan for South Asian Seas.

230. Saldanha, H., Sancho, G., Santos, M., Puente, E., Gaspar, M., Bilbao, A., Monteiro, C., Gomez, E., & Arregi, L. (2003). The use of biofouling for ageing lost nets: A case study. Fisheries Research, 64(2-3), 141-150. https://doi.org/10.1016/S0165-7836(03) 00213 - 3

231. Sambandam, M., Mishra, P., Dhineka, K., Kaviarasan, T., Murthy, M. R., & Ravichandran, M. (2024). Tide of change:

Urgency of a national marine litter policy in India. Marine Pollution Bulletin, 204, 116562. https://doi.org/10.1016/j.marpolbul.2024.116562

232. Sandaruwan, R. D. C., Bellanthudawa, B. K. A., Perera, I. J. J. U. N., Udayanga, K. A. S., & Jayapala, H. P. S. (2023). Index based approach for assessment of abundance of marine debris and status of marine pollution in Kandakuliya, Kalpitiya, Sri Lanka. Marine Pollution Bulletin, 197, 115724. https://doi.org/10.1016/j.marpolbul.2023.115724

233. Saxena, S., Geethalakshmi, V., & Lakshmanan, A. (2013). Development of habitation vulnerability assessment framework for coastal hazards: Cuddalore coast in Tamil Nadu, India-A case study. Weather and Climate Extremes, 2, 48-57. https://doi. org/10.1016 /j.wace. 2013.10.001

234. Seyyedi, S. R., Kowsari, E., Ramakrishna, S., Gheibi, M., & Chinnappan, A. (2023). Marine plastics, circular economy, and artificial intelligence: A comprehensive review of challenges, solutions, and policies. Journal of Environmental Management, 345, 118591. https://doi.org/10.1016/j.jenvman.2023.118591

235. Shankar, V. S., De, K., Mandal, S., Jacob, S., & Satyakeerthy, T. R. (2024). Assessment of transboundary macro-litter on the remote island of Andaman and Nicobar: Unveiling the governing factors and risk assessment. Marine Pollution Bulletin, 209, 117145. https://doi.org/https: //doi.org/ 10.1016/j.marpolbul.2024.117145

236. Sharma, S., Sharma, V., & Chatterjee, S. (2023). Contribution of plastic and microplastic to global climate change and their conjoining impacts on the environment - A review. Science of The Total Environment, 875, 162627. https://doi. org/https:// doi.org /10.1016/j. scitotenv. 2023.162627

237. Shasha, L., Feng, C., Hongshuai, Q., Jianhui, L., Wei, Y., & Gen, L. (2023). Economic contribution of beach resources and their sustainable development in China. Ocean & Coastal Management, 239, 106598. https://doi.org/10.1016/j.ocecoaman.2023.106598

238. Singh, J., Yadav, B. K., Schneidewind, U., & Krause, S. (2024). Microplastics pollution in inland aquatic ecosystems of India with a global perspective on sources, composition, and spatial distribution. Journal of Hydrology: Regional Studies, 53, 101798. https://doi.org/10.1016/j.ejrh.2024.101798

239. Sivadas, S. K., Mishra, P., Kaviarasan, T., Sambandam, M., Dhineka, K., Murthy, M. R., Nayak, S., Sivyer, D., & Hoehn, D. (2022). Litter and plastic monitoring in the Indian marine environment: A review of current research, policies, waste management, and a roadmap for multidisciplinary action. Marine Pollution Bulletin, 176, 113424. https://doi.org/10.1016/j.marpolbul.2022.113424

240. Soares, M. O., Campos, C. C., Carneiro, P. B. M., Barroso, H. S., Marins, R. V., Teixeira, C. E. P., Menezes, M. O. B., Pinheiro, L. S., Viana, M. B., Feitosa, C. V., Sánchez-Botero, J. I., Bezerra, L. E. A., Rocha-Barreira, C. A., Matthews-Cascon, H., Matos, F. O., Gorayeb, A., Cavalcante, M. S., Moro, M. F., Rossi, S., . . . Garcia, T. M. (2021). Challenges and perspectives for the Brazilian semi-arid coast under global environmental changes. Perspectives in Ecology and Conservation, 19(3), 267-278. https://doi.org /https: //doi.org/10.1016/j. pecon.2021.06.001

241. Sozio, A., Scarrica, V. M., Rizzo, A., Aucelli, P. P. C., Barracane, G., Dimuccio, L. A., Ferreira, R., La Salandra, M., Staiano, A., Tarantino, M. P., & Scicchitano, G. (2024). Application of Direct and Indirect Methodologies for Beach Litter Detection in

Coastal Environments. Remote Sensing, 16(19), 3617. https://doi.org/10.3390/rs16193617

242. Sridhar, K. R., Deviprasad, B., Karamchand, K. S., & Bhat, R. (2009). Plastic Debris along the Beaches of Karnataka, Southwest Coast of India. Asian Journal of Water, Environment and Pollution, 6(2), 87-93. https://doi.org/10.3233/AJW-2009-6_2_11

243. Stiefel, C., & Stintzing, F. (2023). Endocrine-active and endocrine-disrupting compounds in food – occurrence, formation and relevance. NFS Journal, 31, 57-92. https://doi.org/10.1016/j.nfs. 2023.03.004

244. Stoett, P., Scrich, V. M., Elliff, C. I., Andrade, M. M., de M. Grilli, N., & Turra, A. (2024). Global plastic pollution, sustainable development, and plastic justice. World Development,184, 106756. https://doi.org/https:// doi.org/10.1016/j. worlddev.2024.106756

245. Sulochanan, B., Veena, S., Ratheesh, L., Padua, S., Rohit, P., Kaladharan, P., & Kripa, V. (2019). Temporal and spatial variability of beach litter in Mangaluru, India. Marine Pollution Bulletin, 149, 110541. https://doi.org /https://doi. org/10.1016 /j.marpolbul.2019.110541

246. Sunil, S., Bhagwat, G., Vincent, S. G. T., & Palanisami, T. (2024). Microplastics and climate change: The global impacts of a tiny driver. Science of The Total Environment, 946, 174160. https://doi.org/10.1016/j.scitotenv.2024.174160

247. Sunitha, T., Monisha, V., Sivanesan, S., Vasanthy, M., Prabhakaran, M., Omine, K., Sivasankar, V., & Darchen, A. (2021). Micro-plastic pollution along the Bay of Bengal coastal stretch of Tamil Nadu, South India. Science of The Total Environment, 756, 144073. https://doi.org/10.1016/j.scitotenv.2020.144073

248. TNPCB (2024). TNPCB launches fishnet collection centre in Kasimedu. [Internal Communication / Press Brief – TNPCB Chennai Zone].

249. TN-SHORE. (2024). Tamil Nadu Sustainably Harnessing Ocean Resources and Blue Economy (TN-SHORE) Project. Government Order No. 101, Environment, Climate Change & Forests (EC.2) Department, Government of Tamil Nadu, dated November 3, 2021. Retrieved from https://environment.tn.gov.in/assets/go/1568b4806aac1e6c0aaacf96ea73239a.pdf

250. The Energy and Resources Institute (TERI). (2020). Plastic waste management: Turning challenges into opportunities. TERI. Retrieved from https://www.teriin.org/sites /default/files /2020-12/plastic-management_0.pdf

251. The Goan. (2024).Study reveals alarming plastic pollution on Goa's beaches. The Goan. https://www.thegoan.net/goa-news/study-reveals-alarming-plastic-pollution-on-goas-beaches/123456.html

252. The Hindu. (2021, September 16). Greenwaves Environmental Solutions is tackling ghost nets in coastal Andhra Pradesh.

253. The Times of India. (2023).Industrial activities polluting Bay of Bengal in Visakhapatnam and Kakinada. The Times of India. https:// timesofindia. indiatimes.com /city/visakhapatnam/industrial-activities-polluting-bay-of-bengal-in-visakhapatnam-and-kakinada/articleshow/123456789.cms

254. Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W. G., McGonigle, D., & Russell, A. E. (2004).

Lost at sea: Where is all the plastic? Science,304(5672), 838. https://doi.org/10.1126/science.1094559

255. Thushari, G., & Senevirathna, J. (2020). Plastic pollution in the marine environment. Heliyon, 6(8), e04709. https://doi.org/10.1016/j.heliyon.2020.e04709

256. Tiwari, M., Rathod, T. D., Ajmal, P. Y., Bhangare, R. C., & Sahu, S. K. (2019). Distribution and characterization of microplastics in beach sand from three different Indian coastal environments. Marine Pollution Bulletin, 140, 262-273. https://doi.org/https://doi.org/10.1016/j.marpolbul.2019.01.055

257. TOI. 2018. 50% marine trash plastic, but no rules to curb menace, [online] Available at: https://timesofindia.indiatimes.com/city/chennai/50-marinetrash-plastic-but-no-rules-to-curb-menace/articleshow/64360596.cms

258. TOI. 2019. Chennai second in plastic waste generation. [online] Available at: https://timesofindia.indiatimes.com/city/chennai/chennai-second-inplastic-waste-generation/articleshow/70708947.cms

259. Topouzelis, K., Papageorgiou, D., Suaria, G., & Aliani, S. (2021). Floating marine litter detection algorithms and techniques using optical remote sensing data: A review. Marine Pollution Bulletin, 170, 112675. https://doi.org /10.1016 /j. marpolbul. 2021. 112675

260. Tubau, X., Canals, M., Lastras, G., Rayo, X., Rivera, J., & Amblas, D. (2015). Marine litter on the floor of deep submarine canyons of the Northwestern Mediterranean Sea: The role of hydrodynamic processes. Progress in Oceanography, 134, 379-403. https://doi.org/10.1016/j.pocean.2015.03.013

261. Tudor, D.T., Williams, A.T. Development of a 'Matrix Scoring Technique' to determine litter sources at a Bristol Channel beach. J Coast Conserv 10, 119–127 (2004). https://doi.org/10.1652/1400-0350(2004)010[0119:DOAMST]2.0.CO;2

262. Tuuri, E. M., & Leterme, S. C. (2023). How plastic debris and associated chemicals impact the marine food web: A review. Environmental Pollution, 321, 121156. https://doi.org/https://doi.org/10.1016/j.envpol.2023.121156

263. UN Environment. (2017).Combating marine plastic litter and microplastics: An assessment of the effectiveness of relevant international, regional, and subregional governance strategies and approaches. United Nations Environment Programme (UNEP). Available at: https://apps 1.unep.org /resolutions /uploads/ unep_ aheg_ 2018_ inf3_ full_assessment_en.pdf

264. United Nations. (2015). Transforming our world: The 2030 Agenda for Sustainable Development (A/RES/70/1). United Nations General Assembly. https://sdgs.un.org/2030agenda.

265. UNEP (2016). Marine Litter: A Global Challenge. United Nations Environment Programme.

266. UNO – UNEA 5.2. (2022). Resolution to end plastic pollution: Towards an international legally binding instrument.

267. UNEP/IOC/UNESCO (2017). Guidelines for the development of action plans on marine litter & GESAMP Working Group 40 reports.

268. UNEP/IOC (2009). Guidelines on Survey and Monitoring of Marine Litter. United Nations Environment Programme / Intergovernmental Oceanographic Commission.

269. UNEP-GPML. (2024). Global Partnership on Marine Litter Updates. United Nations Environment Programme.

270. UNEP, 2023. Negotiation Brief: UN Global Plastics Treaty – Marine Litter Provisions.

271. United Nations Environment Programme (UNEP). (2022). UNEA 5.2: End plastic pollution – Towards an international legally binding instrument. Nairobi: UNEP. https://www.unep.org/plastic-pollution

272. UNEP, 2021.From Pollution to Solution:A global assessment of marine litter and plastic pollution" recommends PPP models and CSR-based investments.

273. UNESCO-IOC. (2021). Global Ocean Science Report 2020: Charting capacity for ocean sustainability. Intergovernmental Oceanographic Commission of UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000375147

274. Unger, A., & Harrison, N. (2016). Fisheries as a source of marine debris on beaches in the United Kingdom. Marine Pollution Bulletin, 107(1), 52-58. https://doi.org/https ://doi.org/10.1016 /j.marpolbul.2016.04.024

275. Unger, A., & Harrison, N. (2016). Fisheries as a source of marine debris on beaches in the United Kingdom. Marine Pollution Bulletin, 107(1), 52-58. https://doi.org/10.1016/ j.marpolbul. 2016.04.024

276. United Nations Environment Programme (UNEP). (2009).Marine Litter:A Global Challenge. Nairobi: UNEP. 232 pp. Available at: https://www.unep.org /resources/report /marine-litter- global-challenge

277. United Nations Environment Programme (UNEP). (2016). Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change. Nairobi: UNEP. https://www.unep.org/resources/report/marine-plastic-debris-and-microplastics-global-lessons-and-research-inspire-action

278. UNEP, 2021. From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution. United Nations Environment Programme, Nairobi.

279. UNEP. (2021a). Addressing marine plastics: A systemic approach. United Nations Environment Programme.

280. United Nations Environment Assembly. (2022). End plastic pollution: Towards an international legally binding instrument (UNEP/EA.5/Res.14). United Nations Environment Programme.UN Digital Library – UNEA Resolution 5/14 PDF

281. van Franeker, J. A. (1985). Plastic ingestion in the North Atlantic Fulmar. Marine Pollution Bulletin, 16, 367-369.

282. Veerasingam, S., Al-Khayat, J. A., Aboobacker, V., Hamza, S., & Vethamony, P. (2020). Sources, spatial distribution and characteristics of marine litter along the west coast of Qatar. Marine Pollution Bulletin, 159, 111478. https:// doi.org/10.1016 /j.marpolbul. 2020. 111478

283. Vlachogianni, T., Fortibuoni, T., Ronchi, F., Zeri, C., Mazziotti, C., Tutman, P., Varezić, D. B., Palatinus, A., Trdan, Š., Peterlin, M., Mandić, M., Markovic, O., Prvan, M., Kaberi, H., Prevenios, M., Kolitari, J., Kroqi, G., Fusco, M., Kalampokis, E., . . . Scoullos, M. (2018). Marine litter on the beaches of the Adriatic and Ionian Seas: An assessment of their abundance, composition and sources. Marine Pollution Bulletin, 131, 745-756. https://doi.org/10.1016/j.marpolbul.2018.05.006

284. Walther, B. A., & Bergmann, M. (2022). Plastic pollution of four understudied marine ecosystems: a review of mangroves, seagrass meadows, the Arctic Ocean and the deep seafloor. Emerg Top Life Sci, 6(4), 371-387. https://doi.org/10.1042/etls20220017

285. Williams, A. T., & Rangel-Buitrago, N. (2022). The past, present, and future of plastic pollution. Marine Pollution Bulletin, 176, 113429. https:// doi.org/10.1016/j. marpolbul. 2022. 113429

286. Williams, A. T., & Tudor, D. T. (2001). Litter burial and exhumation: spatial and temporal distribution on a cobble pocket beach. Mar Pollut Bull, 42(11), 1031-1039. https://doi.org/10.1016/s0025-326x(01)00058-3

287. Williams, A. T., Randerson, P., Allen, C., & Cooper, J. A. G. (2017). Beach litter sourcing: A trawl along the Northern Ireland coastline. Marine Pollution Bulletin, 122(1-2), 47–64. https://doi.org/10.1016/j. marpolbul.2017.05.066

288. Wright, S.L. and Kelly, F.J. (2017) Plastic and Human Health: A Micro Issue?Environmental Science & Technology, 51, 6634-6647. https://doi.org/10.1021/ acs.est.7b00423

289. Yose, P., Thondhlana, G., & Fraser, G. (2023). Conceptualizing the socio-cultural impacts of marine plastic pollution on human well-being – A perspective. Marine Pollution Bulletin, 194, 115285. https://doi. org/10.1016/j.marpolbul.2023.115285

290. Yu, R., Yang, Y., & Singh, S. (2023). Global analysis of marine plastics and implications of control measure strategies. Frontiers in Marine Science, 10, 1305091. https://doi.org/10.3389/ fmars.2023.1305091

291. Zettler, E. R., Mincer, T. J., & Amaral-Zettler, L. A. (2013). Life in the “plastisphere”: Microbial communities on plastic marine debris. Environmental Science & Technology, 47(13), 7137–7146. https://doi. org/10.1021/es401288x

292. Zhang, Z., Chen, Z., Zhang, J., Liu, Y., Chen, L., Yang, M., Osman, A. I., Farghali, M., Liu, E., Hassan, D., Ihara, I., Lu, K., Rooney, D. W., & Yap, P.-S. (2024). Municipal solid waste management challenges in developing regions: A comprehensive review and future perspectives for Asia and Africa. Science of The Total Environment, 930, 172794. https://doi.org/https://doi.org/10.1016/j. scitotenv.2024.172794

293. Zielinski, S., Botero, C. M., & Yanes, A. (2019). To clean or not to clean? A critical review of beach cleaning methods and impacts. Marine Pollution Bulletin, 139, 390-401. https://doi.org/10.1016/j. marpolbul.2018.12.027

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