ISSN 3139-4981

The Universal Scholar Journal

International Peer-Reviewed | Open Access | Multidisciplinary Research Journal

Vol I, Issue IV, Monthly, August, 2026

ISSN 3139-4981

THE UNIVERSAL SCHOLAR JOURNAL

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Vol. I, Issue IV, Monthly, August, 2026

ISSN 3139-4981

THE UNIVERSAL SCHOLAR JOURNAL (***Internationally Peer Reviewed Journal***)

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ISSN 3139-4981

Impact of Microplastic Pollution on Marine Fauna of the Malabar Coast: A Review of Current Evidence, Ecological Risks, and Research Directions

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Abstract

The Malabar Coast, spanning the tropical, monsoon-influenced shoreline of Kerala and adjoining parts of Karnataka on the south-western seaboard of India, supports one of the country's most productive artisanal and commercial fisheries as well as ecologically sensitive estuaries, backwaters, and mangrove-fringed wetlands. Over the past decade, a growing body of regional research has documented the widespread occurrence of microplastics (MPs) in the coastal waters, sediments, and biota of this region, raising concern over their ecological and food-safety implications. This review synthesises published field and laboratory evidence on microplastic contamination along the Malabar Coast and adjoining southwest coast of India, with particular attention to its presence and effects in commercially and ecologically important marine fauna, including finfish, bivalve molluscs, and other invertebrates. Reported polymer types are dominated by polyethylene, polypropylene, polyethylene terephthalate, nylon, and polyamide, occurring predominantly as fibres and fragments in gastrointestinal tracts, gill tissue, and, in some cases, edible musculature. Drawing on the wider global toxicological literature, the review outlines the principal mechanisms of harm, namely physical injury and gut blockage, oxidative stress, immune and endocrine disruption, reduced feeding and energy budgets, and the vector effect by which microplastics adsorb and transport persistent organic pollutants and heavy metals into tissues. The review further considers the implications for coastal fisheries, food safety, and human exposure, before identifying critical gaps in region-specific ecotoxicological data, standardised sampling protocols, and long-term monitoring along the Malabar Coast. The article concludes with recommendations for coordinated regional monitoring, source-reduction policy, and community-based mitigation measures suited to Kerala's densely populated, fishery-dependent coastline.

Keywords: Microplastics, Marine Pollution, Malabar Coast, Kerala Marine Fauna, Bioaccumulation, Ecotoxicology, Fisheries

Introduction

Plastic debris has become one of the most persistent and visible contaminants of the global marine environment. Once discarded, plastic items degrade slowly under ultraviolet radiation, mechanical abrasion, and biological weathering into progressively smaller particles, giving rise to microplastics (MPs), conventionally defined as plastic fragments, fibres, films, or granules smaller than 5 mm (Andrady, 2011; Thompson et al., 2004). Owing to their small size, buoyancy characteristics, and chemical stability, microplastics are readily transported across coastal and open-ocean environments, where they accumulate in sediments, the water column, and living tissues (Auta, Emenike, & Fauziah, 2017).

The Malabar Coast, the historically and geographically distinct stretch of India's south-western shoreline extending through Kerala and into coastal Karnataka, is characterised by a dense network of estuaries, backwaters, lagoons, and river mouths that connect a heavily populated hinterland to the Arabian Sea. This hydrological connectivity, combined with high population density, intensive fishing and aquaculture activity, tourism, and inadequate solid-waste management infrastructure in many coastal towns, creates favourable conditions for the land-to-sea transport of plastic waste (Padmachandran, Sreethu, Nasrin, Muthuchamy, & Muthukumar, 2024). The coast additionally supports economically vital fisheries for sardine, mackerel, anchovies, and shrimp, alongside traditional mussel and clam harvesting, making the question of microplastic contamination one of both ecological and public-health significance (Mashirin & Chitra, 2024).

A series of independent field investigations conducted over the last several years, spanning estuaries, backwaters, and coastal fishing grounds from Kasaragod in the north to Kochi and Kayamkulam further south, have confirmed that microplastics are now a ubiquitous component of the Malabar Coast's marine and estuarine environment (Gupta et al., 2021; Radhakrishnan et al., 2021; Sruthy & Ramasamy, 2017; Suresh, Vijayaraghavan, Saranya, Neethu, & Aneesh, 2020). These studies have progressively extended from characterising microplastic abundance in water and sediment towards documenting their uptake by resident fauna, including finfish, bivalves, and crustaceans that form the basis of local diets and livelihoods. Despite this expanding evidence base, comprehensive syntheses that draw together the scattered regional literature specifically for the Malabar Coast, and that connect it to the

broader mechanistic understanding of microplastic toxicology developed in the international literature, remain limited.

This review therefore aims to (i) summarise the documented occurrence and characteristics of microplastics in the coastal and estuarine waters of the Malabar Coast; (ii) synthesise the evidence on microplastic uptake and its physiological, cellular, and behavioural consequences in resident marine fauna; (iii) situate these regional findings within the broader mechanistic framework established by global ecotoxicological research; and (iv) identify priority gaps and directions for future research and management along this ecologically and economically significant coastline.

Materials and Methods

This article follows a narrative-review methodology appropriate to a regionally focused synthesis of an actively developing research area. Peer-reviewed journal articles, indexed in databases such as ScienceDirect, SpringerLink, and Wiley Online Library, were identified using combinations of the search terms "microplastic," "Malabar Coast," "Kerala," "southwest coast of India," "marine fauna," "fish," "bivalve," and "estuary." Studies were prioritised for inclusion if they reported primary field or laboratory data on microplastic occurrence, characterisation, or biological effects within the Malabar Coast or the broader southwest coast of India, a region with which the Malabar Coast is hydrologically and ecologically continuous. Global studies on microplastic toxicology were additionally reviewed to provide the mechanistic context needed to interpret regional field observations, since region-specific experimental toxicology remains sparse. Findings were synthesised thematically around (a) environmental occurrence, (b) uptake by marine fauna, (c) physiological and toxicological mechanisms, and (d) implications for fisheries, food safety, and management. This review does not present new primary field or laboratory data; readers seeking to publish original empirical findings from the Malabar Coast are encouraged to design a field-sampling and biomonitoring study using the protocols referenced herein.

Occurrence and Characteristics of Microplastics along the Malabar Coast

Field surveys across the Malabar Coast and adjoining southwest coast of India have consistently reported the presence of microplastics in coastal seawater, estuarine sediment, and

beach substrates. In the Kavvayi and Kumbla backwaters of the northern Malabar region in Kasaragod district, sediment concentrations averaged approximately 99.5 particles per kilogram in the Kavvayi backwater and 96.6 particles per kilogram in the Kumbla backwater, with synthetic elastomers, polyamide, polyethylene, polyester, polyurethane, and polypropylene identified as the dominant polymer types through confocal Raman spectroscopy (Padmachandran et al., 2024). Elevated microplastic loads were also detected in co-occurring clams, prawns, and fish, indicating active transfer from sediment into the local food web.

Further south, a comprehensive assessment of water, sediment, and fish tissue along the Malabar Coast in northwest Kerala using Fourier-transform infrared (FTIR) spectroscopy identified six predominant polymer types, including high-density polyethylene, polyethylene terephthalate, and nylon, with fragments (48.1 per cent), fibres (28.8 per cent), filaments (19.2 per cent), and granules (3.9 per cent) constituting the principal morphotypes recovered from commercially important fish species (Mashirin & Chitra, 2024). Comparable morphotype and polymer distributions have been reported from other estuarine systems along Kerala's coast, including the Kayamkulam estuary, where sediment concentrations and their relationship to nearby anthropogenic inputs, such as fishing harbours and urban drainage, were characterised in detail (Radhakrishnan et al., 2021), and the central west coast estuarine system, where spatial and seasonal variation in microplastic abundance was linked to riverine discharge and monsoonal flushing (Gupta et al., 2021).

Historically, the first documented evidence of microplastic contamination in an Indian lake or estuarine sediment came from Vembanad Lake, Kerala's largest wetland system and a Ramsar-designated site, where fibre-dominated contamination was recorded in both lake and estuarine sediments (Sruthy & Ramasamy, 2017). Subsequent work in the same system quantified microplastic abundance in commercially important bottom-dwelling finfish and shellfish, confirming that contamination detected in abiotic compartments translates into measurable body burdens in harvested species (Nikki et al., 2021). Similarly, surveys of the Cochin coastal zone have documented consistent microplastic distribution patterns linked to shipping, fishing, and urban effluent sources (Suresh et al., 2020). Taken together, these studies indicate that microplastic contamination is not confined to isolated hotspots but is a persistent, basin-wide feature of the Malabar Coast's estuarine and nearshore environment, with fibres and

fragments of polyethylene, polypropylene, and polyester consistently dominating recovered particles across independent studies and sampling locations.

Uptake and Effects in Marine Fauna

Finfish

Multiple independent surveys confirm that microplastics are ingested by, and accumulate in, a wide range of demersal and pelagic finfish species harvested along the Malabar and adjoining Kerala coast. In the Malabar Coast assessment of Mashirin and Chitra (2024), gastrointestinal tissues exhibited the highest microplastic concentrations among the tissues examined, followed by gill tissue, with particle sizes typically below one millimetre. Beyond simple presence and abundance, toxicological exposure studies conducted on the pearlspot, Etroplus suratensis, a food fish widely cultured in Cochin estuarine waters, demonstrated that polyvinyl chloride microplastic exposure produced measurable physiological impacts, underscoring that contamination documented in field surveys corresponds to genuine biological stress under experimental conditions (Vijayaraghavan et al., 2022). The consistent recovery of microplastics from gill tissue across studies is notable because gills are respiratory as well as osmoregulatory organs; particle lodgement in gill filaments has the potential to impair gas exchange and ionic regulation independent of any effect mediated through the gut.

Bivalve Molluscs

Filter-feeding bivalves are widely regarded as sentinel organisms for microplastic pollution because their feeding mode filters large volumes of water and non-selectively captures suspended particles. A field and laboratory investigation of the Asian green mussel, Perna viridis, sampled from its most extensive natural beds along the northern Malabar Coast between Kasaragod and Kozhikode, provided the first comprehensive evidence of microplastic ingestion in this commercially important species, reporting significantly higher microplastic loads in intertidal mussels than in those from deeper water, a predominance of fibrous polypropylene and polyethylene terephthalate particles, and, under laboratory exposure, measurable impairment of algal clearance rates, indicating that ingested microplastics interfere with the mussels' normal filter-feeding physiology (Remanan, Sahadevan, Anju, Ankitha, Lal,

& Sanjeevan, 2025). Because Perna viridis is both an ecologically important reef-forming species and a major component of Kerala's shellfish fishery, this reduction in feeding efficiency carries implications for both individual growth and the wider productivity of mussel beds.

Broader Faunal and Ecosystem Considerations

Although finfish and bivalves dominate the published Malabar Coast literature, the underlying sediment and water-column contamination documented across backwater and estuarine systems implies broader exposure risk to other resident fauna, including benthic crustaceans, meiofauna, and juvenile life stages that use estuaries and mangrove-fringed backwaters as nursery habitat. The consistent detection of microplastics in prawns alongside fish and clams in the Kavvayi and Kumbla backwaters (Padmachandran et al., 2024) suggests that trophic transfer between sediment-dwelling and pelagic organisms is already occurring within these systems, though direct evidence for higher-order trophic transfer up the Malabar Coast food web remains limited and is an important target for future research.

Toxicological Mechanisms of Microplastic-Induced Harm

The physiological and cellular consequences of microplastic exposure in marine fauna, established primarily through the international ecotoxicological literature, provide the mechanistic context needed to interpret the field observations reported from the Malabar Coast. Several convergent pathways of harm have been documented across taxa:

Physical and mechanical effects. Ingested particles can cause gut blockage, false satiation, and abrasive damage to gastrointestinal epithelia, reducing effective food intake and, in filter feeders such as mussels, interfering directly with ciliary feeding mechanisms, consistent with the reduced algal clearance observed in Perna viridis from the Malabar Coast (Remanan et al., 2025).

Oxidative stress and cellular damage. Microplastic exposure has been repeatedly shown to elevate reactive oxygen species production and perturb antioxidant enzyme activity, including superoxide dismutase, catalase, and glutathione-related enzymes, across a wide range of marine invertebrates and fish, with consequences for cell membrane integrity and tissue-level damage (Auta et al., 2017; Rezania et al., 2018).

Vector effects for co-contaminants. Owing to their high surface-area-to-volume ratio and hydrophobic surface chemistry, microplastics readily adsorb persistent organic pollutants, plasticiser additives, and trace metals from the surrounding water, effectively acting as vectors that concentrate and deliver these co-contaminants into the tissues of organisms that ingest them (Hermabessiere et al., 2017). This mechanism is of particular concern along the Malabar Coast given the co-occurrence of industrial, agricultural, and untreated domestic effluent inputs into the region's estuaries.

Endocrine, immune, and reproductive disruption. Sub-lethal exposure to microplastics and their associated chemical additives has been linked in laboratory studies to altered endocrine signalling, immune suppression, and impaired reproductive output in fish and invertebrates, effects that would not necessarily be apparent from field abundance data alone but that carry significant implications for population-level productivity (Gall & Thompson, 2015; Rezania et al., 2018).

Behavioural and energetic effects. Reduced feeding efficiency, altered predator-avoidance behaviour, and diversion of metabolic energy towards particle handling and detoxification have been documented as sub-lethal but ecologically meaningful consequences of chronic microplastic exposure, with direct relevance to the reduced clearance rates reported in Malabar Coast mussel populations (Remanan et al., 2025).

Collectively, these mechanisms indicate that the ecological risk posed by microplastics along the Malabar Coast extends well beyond the simple presence of particles in tissue, encompassing sub-lethal physiological costs that may accumulate over the lifespan of long-lived, sessile, or site-attached species such as mussels, and that may propagate through local food webs via trophic transfer.

Implications for Fisheries, Food Safety, and Human Communities

The Malabar Coast supports dense coastal populations for whom fish, mussels, and clams represent both a dietary staple and a significant source of livelihood. The demonstrated presence of microplastics in the edible tissues, and not merely the gastrointestinal tracts, of pelagic fish species consumed in Kerala has been highlighted as a direct pathway of human dietary exposure to microplastics (Mashirin & Chitra, 2024), a concern reinforced by

comparable findings from other Indian coastal fisheries. Because gill tissue, which is typically discarded, and gastrointestinal tissue, which is usually removed during cleaning, showed the highest particle burdens in several studies, appropriate food-handling and cleaning practices may meaningfully reduce, though not eliminate, dietary exposure. The presence of microplastics as vectors for adsorbed pollutants further compounds the potential food-safety concern, since edible tissue contamination could carry not only plastic particles themselves but also co-transported chemical contaminants (Hermabessiere et al., 2017).

Beyond direct human health considerations, sub-lethal physiological effects on commercially important species, including reduced feeding efficiency in mussels and cellular stress responses documented in exposed fish, carry the potential to affect growth rates, reproductive output, and ultimately the productivity of fisheries and aquaculture operations that underpin coastal livelihoods along the Malabar Coast. Given the socio-economic importance of small-scale and traditional fisheries in this region, these ecological risks are inseparable from questions of livelihood security and rural development.

Research Gaps and Future Directions

Despite the accumulating body of regional evidence, several important gaps remain in the understanding of microplastic impacts on Malabar Coast marine fauna. First, the great majority of published studies are descriptive, documenting the occurrence and abundance of microplastics in environmental matrices and tissues, while controlled exposure studies quantifying dose-dependent physiological and reproductive effects in ecologically and commercially important local species remain scarce, with the pearlspot toxicity study of Vijayaraghavan et al. (2022) a notable exception. Second, sampling methodologies, including mesh sizes, digestion protocols, and polymer-identification techniques, vary across the existing Malabar Coast literature, limiting direct comparability between studies and complicating the establishment of region-wide baselines. Third, long-term, seasonally resolved monitoring programmes that track microplastic loads across monsoon and post-monsoon periods, when riverine discharge and land-based runoff vary substantially, are largely absent. Fourth, evidence for trophic transfer of microplastics and their associated contaminants from lower to higher trophic levels within Malabar Coast food webs, including to apex predatory fish and to human consumers, remains indirect. Finally, there is a need for region-specific socio-economic

and risk-communication research examining how coastal fishing communities perceive and respond to microplastic contamination, to inform the design of locally appropriate mitigation and outreach strategies.

Future research along the Malabar Coast would benefit from standardised, harmonised sampling and analytical protocols; controlled laboratory exposure studies using regionally relevant species and environmentally realistic particle concentrations; integration of microplastic monitoring into existing fisheries and water-quality surveillance programmes; and interdisciplinary collaboration linking marine ecotoxicology with public health and coastal livelihoods research.

Conclusion

The available evidence demonstrates that microplastic contamination is now a well-established and geographically widespread feature of the Malabar Coast's estuaries, backwaters, and nearshore waters, with consistent detection in sediments, the water column, and the tissues of commercially and ecologically important marine fauna, including finfish and bivalve molluscs. Field studies from the Kavvayi and Kumbla backwaters, the wider Malabar Coast fishery, Vembanad Lake, the Kayamkulam and Cochin estuarine systems, and the central west coast collectively indicate that fibres and fragments composed of polyethylene, polypropylene, polyethylene terephthalate, and related polymers are the dominant contaminants, with gastrointestinal and gill tissues showing the highest particle burdens. When interpreted alongside the broader global toxicological literature, these findings point to plausible sub-lethal physiological costs for exposed organisms, including impaired feeding, oxidative stress, and vector-mediated co-contaminant exposure, with corresponding implications for fisheries productivity, food safety, and the wellbeing of coastal communities that depend on this ecosystem. Addressing these risks will require sustained, standardised regional monitoring, targeted ecotoxicological research on locally important species, and coordinated policy action to reduce land-based and marine sources of plastic waste along this densely populated and ecologically significant coastline.

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