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# Microplastics in small Island ecosystems: Integrating evidence on distribution, bioaccumulation, and social-ecological impacts

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## ABSTRACT

**Background**: Small island ecosystems are highly vulnerable to marine plastic pollution due to geographic isolation, limited waste-management capacity, and exposure to converging ocean currents. Yet, integrated syntheses linking contamination patterns with ecological and socio-economic impacts remain scarce. **Methods**: A structured literature review of peer-reviewed studies published between January 2020 and August 2025 was conducted using the Scopus database and targeted reference screening. Empirical studies measuring microplastics in island or near-island environments and addressing trophic transfer or socio-economic impacts were prioritized, while methodological differences were considered qualitatively in interpreting evidence strength. **Findings:** Sediments consistently act as long-term sinks in island systems, often exhibiting orders-of-magnitude higher microplastic concentrations than concurrent water samples. Fragments and fibres dominate particle morphologies, with polyethylene, polypropylene, and polystyrene the most common polymers. Microplastics are ingested across trophic levels, but evidence for systematic trophic biomagnification remains mixed. Sublethal effects and contaminant or pathogen transfer reduce ecosystem productivity and fisheries performance, while socio-economic impacts include declining seafood quality and disproportionate burdens on vulnerable island communities. **Conclusion**: Microplastic pollution in small islands presents coupled ecological and social risks that remain understudied and are constrained by methodological heterogeneity. Priority actions include standardized sampling/analysis protocols, long-term monitoring, realistic exposure experiments, and targeted mitigation (waste management upgrades, community-based interventions). **Novelty/Originality of this article:** This is the first structured synthesis (2020–2025) explicitly integrating occurrence, trophic-level bioaccumulation, and socio-ecological impacts of microplastics in small-island ecosystems, highlighting evidence gaps and policy-relevant research priorities.

**KEYWORDS**: bioaccumulation; marine sediments; microplastic; small island ecosystems; socio-ecological impacts.

## 1. Introduction

Plastic manufacture worldwide has increased exponentially since the mid-twentieth century, from negligible volumes in the 1950s when synthetic polymers were first entering wide use (Geyer et al., 2017). Between 1950 and 2017, some 9.2 billion metric tons of plastic were manufactured, the vast majority designed for one-off use (Williams & Rangel-Buitrage, 2022). Yet, the entirety of only about 9% of this cumulative production has been recycled in the world (OECD, 2022), highlighting a structural inefficiency of the world's waste management. Growth in production has been accompanied by increased ocean pollution

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through plastic accumulation. Plastic rubbish was first witnessed in the seas near half a century ago when world production was less than 50 million metric tons (Law, 2017). Today, an estimated 4.8–12.7 million metric tons of plastics are emitted into the ocean annually as macro- and microplastic fragments, mainly from mismanaged waste—approximately 40% of total plastic production (Worm et al., 2017).

Land use is commonly agreed upon to be the greatest contributor to marine plastic pollution, with approximately 80% of all inputs by riverine and runoff pathways (Wang et al., 2024). River networks are major vectors for onshore waste, carrying plastic to coastlines by point and diffuse sources. Global modeling indicates that around 77% of plastic floating waste is trapped in nearshore waters or beaches within five years of ocean dumping (Onink et al., 2021). Despite occupying only 0.87% of global shorelines, river-dominated coastlines receive more than half of all fluvial plastic inputs, while tide- and wave-dominated coastlines yield smaller shares (Harris et al., 2021). Island seas have offshore ocean circulations such as the Gulf Stream and North Atlantic Subtropical Gyre, which enable refuse to be carried far away, bridging remote archipelagos with mainland sources (Cardoso & Caldeira, 2021). Together, these transport mechanisms position small island ecosystems as chronic nearshore reservoirs and long-term sinks for ocean plastic trash, substantiating the synergistic impacts of geographic remoteness, limited waste-management capability, and susceptibility to converging ocean current systems.

Microplastics in marine ecosystems have both primary and secondary sources, with the secondary sources accounting for roughly 69–81% of total marine trash (Jolaosho et al., 2025). Primary microplastics are intentionally manufactured (microbeads, synthetic fibers, paint flakes, and tire-wear particles), while secondary microplastics come from the degradation of larger materials by ultraviolet radiation, wear, and chemical weathering (An et al., 2020; Nkin, 2025). Land-based runoff and uncontrolled dumping of wastes are accountable for the majority of these inputs (80–90%), where low-density polymers such as polyethylene (36%) and polypropylene (21%) are the most prevalent (Auta et al., 2017; Jolaosho et al., 2025). These are facilitated by environmental transport and endurance through heteroaggregation, adsorption, and crystallinity and susceptibility to hydrodynamic and meteorological forces.

Microplastic deposition in small island ecosystems is more prone to vulnerability through ecological vulnerability dynamics and physical entrainment. Endemic organisms in such systems generally possess limited adaptive capacity to rapid anthropogenic stress (Horton & Barnes, 2020). Island oceans experience twin stresses: offshore sedimentation by large-scale currents and local terrestrial discharges. Consequently, microplastic burdens frequently prevail along coasts, lagoons, and nearshore sediments, particularly following rain events (Amorim et al., 2024). Vegetated coastal environments such as mangroves, saltmarshes, and seagrass meadows function as natural sinks that take up floating particles; however, degraded areas attain significantly higher microplastic loads compared to their pristine counterparts (Hernán et al., 2024). All of these mechanisms emphasize the function of island systems as temporary receptors and permanent sinks of marine microdebris.

Economic and social factors intensify this pollution even more. In Fiji, microplastics have been detected in coastal waters, sediments, and gut contents of fish, with poor sewage treatment and land-based disposal being primary sources (Ferreira et al., 2020). This pollution diminishes fisheries productivity and seafood market value because commercially valuable species tend to carry plastics (Rivera-Garibay et al., 2024). This, in turn, imposes economic and governance burdens on local fisheries, aquaculture, and tourism (Chaudhry & Sachdeva, 2021; Mofijur et al., 2021). Moreover, ingestion of microplastics and their associated chemicals can induce cytotoxicity, oxidative stress, and immunological impacts in aquatic organisms and human consumers, while public concern among communities that are resource-dependent remains low. These cross-linked social and ecological consequences highlight the coupled character of microplastic pollution as a socio-ecological issue within small island systems.

Socio-ecological systems (SES) theory provides a productive framework through which to examine feedbacks among human beings and the deterioration of the environment in island ecosystems but little empirical evidence exists for trophic levels of systemic biomagnification. Single-taxa bioaccumulation is supported by observations in the field, while laboratory studies demonstrating proof of trophic transfer test organisms at dose rates far above natural (Carbery et al., 2018; Alava, 2020; Miller et al., 2020). Compared to persistent organic pollutants, microplastics have less biomagnification potential, though their adsorptive and co-contaminant transport ability creates additional ecological and toxicological uncertainty (Au et al., 2017).

Despite rapid growth in microplastic research, small island ecosystems—here broadly defined as islands and archipelagic environments characterized by limited land area, strong dependence on coastal resources, and structural vulnerability to external environmental pressures, including but not limited to Small Island Developing States (SIDS)—remain underrepresented in empirical and synthesis studies, even though they function as convergence zones for marine litter while facing limited monitoring and mitigation capacity. Existing literature often treats microplastic distribution, biological uptake, and socio-economic consequences separately, limiting understanding of how contamination propagates across ecological and human systems. This gap is particularly critical in island contexts, where livelihoods, food security, and cultural identity depend strongly on coastal and marine resources. An integrated synthesis is therefore required to clarify how environmental contamination translates into ecological and socio-economic risks.

This study addresses that gap by synthesizing global evidence published between 2020 and 2025 to: (i) review spatial patterns and dominant sources of microplastic contamination in small island environments, (ii) compare evidence for ingestion, bioaccumulation, and potential trophic transfer within island food webs, and (iii) examine socio-ecological consequences for fisheries, seafood safety, and coastal livelihoods. By integrating ecological and human dimensions, this review aims to inform monitoring priorities and support policy-relevant mitigation strategies suited to the practical constraints of small-island contexts.

## 2. Methods

### *2.1 Literature search strategy*

This study conducted a structured literature review to synthesize recent empirical evidence on microplastic contamination, bioaccumulation, and socio-ecological impacts in small island ecosystems. The review focused on peer-reviewed articles published between January 2020 and August 2025, identified through the Scopus database, chosen for its broad interdisciplinary coverage of environmental and marine sciences. Although the primary search period covered 2020–2025, several pre-2020 studies were included where they provided foundational data or methodological benchmarks critical to interpreting recent findings. Searches were limited to English-language publications and employed Boolean operators to capture conceptual and terminological variations using the following string:

TITLE-ABS-KEY ("microplastic*" OR "micro plastic*" OR "micro-plastic*");
AND TITLE-ABS-KEY ("island*" OR "archipelago" OR "small island" OR "SIDS");
AND TITLE-ABS-KEY ("bioaccumul*" OR "ingest*" OR "trophic" OR "food web" OR "ecotox*" OR "ecosystem*" OR "coral reef*" OR "seagrass*" OR "mangrove*" OR "biodiversity" OR "fisheries" OR "seafood" OR "human exposure").

To ensure thematic breadth, additional searches included terms related to bioaccumulation, trophic transfer, seafood, human exposure, and governance. Reference lists of key papers and relevant intergovernmental reports were also screened for complementary data. This approach helped capture a broader range of perspectives and ensured the inclusion of relevant studies that might not have appeared in the primary database search.

*2.2 Inclusion and exclusion criteria*

Inclusion criteria encompassed empirical studies quantifying microplastics in environmental matrices (water, sediment, and biota) within island or coastal contexts, as well as research addressing trophic transfer, food-web interactions, or human exposure, and studies examining the socio-economic dimensions of microplastic pollution. Laboratory-only modeling papers, non-English publications, and grey literature were excluded unless they contained quantitative environmental data. Although the synthesis primarily focused on small island systems, complementary evidence from broader coastal environments was incorporated to contextualize physical and ecological processes where island-specific data remain limited. This inclusion acknowledges the ecological continuity between island and coastal systems while enhancing analytical robustness across diverse geographic settings. Technical and intergovernmental reports were used to complement peer-reviewed studies for contextual or regional insights, but were not weighted as primary evidence in analytical interpretation.

*2.3 Data extraction and analytical framework*

Differences in study design, biological matrices, and analytical approaches were explicitly acknowledged, as they influence interpretation of reported microplastic ingestion, bioaccumulation, and biomagnification. Rather than applying a formal evidence-ranking framework, these differences were discussed qualitatively and integrated into thematic synthesis. From each study, data on publication year, location, matrix type, polymer composition, dominant morphotypes, and biological or socio-economic endpoints were extracted and synthesized into four analytical dimensions, namely occurrence and sources, bioaccumulation and trophic transfer, ecotoxicological and ecosystem effects, as well as socio-ecological impacts.

## 3. Results and Discussion

*3.1 Occurrence and sources in island systems*

Current studies have documented the ubiquity of microplastics in island systems worldwide and concluded that island systems serve as important sinks of sea plastic litter. Reported concentrations vary significantly among matrices of the environment and sites, partly because of methodological variability in sampling design, mesh size, and identification methods of analysis, and site-specific differences in hydrodynamics, population abundance, and anthropogenic pressures such as tourism, fishing, and waste disposal malpractices. Table 1 presents an empirical synthesis of 2020–2025 data, illustrating the spatial distribution of microplastic contamination, dominant particle morphologies, and polymers in exemplary island systems.

The density was highest in coastal sediments in Semak Daun Island, Indonesia (15,200 ± 4,932 MP $kg^{-1}$), derived principally from proximal anthropogenic sources like fish activities and tourism refuse (Patria et al., 2023). Comparable amounts were recorded in Vanuatu sediments (to 33,300 MP $kg^{-1}$) and the Solomon Islands, where low waste collection and high coastal population densities exacerbate leakage into the marine environment (Bakir et al., 2020). On the other hand, comparatively low concentrations were reported for remote or sparsely inhabited islands such as Fiji (19.8 MP $kg^{-1}$), the Maldives (277.9 MP $kg^{-1}$), and Hawaii (≤0.11 MP $m^{-3}$), which receive inputs primarily from long-range oceanic transport driven by dominant current regimes (Ferreira et al., 2020; Patti et al., 2020; Axworthy et al., 2024). In general, these spatial trends indicate island ecosystem microplastic deposition to be highly influenced by regional human pressure and proximity to continental source discharge locations.

Table 1. Summary of microplastic concentrations in island systems reported between 2020 and 2025

| Location | Matrix | Average concentration | Dominant morphotype | Dominant type of polymer | Reference |
|---|---|---|---|---|---|
| Malta (Qalet Marku, Xemxija, Ramla tal-Qortin) | Beach wrack (*Posidonia oceanica*) | 53.14 MP $m^{-2}$ | Fragment | Not reported | Afeniforo et al., 2025 |
| Kane'ohe Bay, Hawai'i, USA | Surface seawater | 0.049–0.11 MP $m^{-3}$ | Fiber | PE | Axworthy et al., 2024 |
| | Sediment | Not quantifiable | | PP | |
| Biawak Island, Indonesia | Sediment | 888.93 MP $kg^{-1}$ dw | Fragment | Not reported | Lewaru et al., 2024 |
| St. Mary's Island, India | Seawater | 218 MP $m^{-3}$ | Fragment | PS | Khaleel et al., 2023 |
| Semak Daun Island, Jakarta Bay, Indonesia | Seawater | 8,200 ± 2,190 MP $m^{-3}$ | Fiber | Not reported | Patria et al., 2023 |
| | Sediment | 15,200 ± 4,932 MP $kg^{-1}$ dw | | | |
| Five coral reef monitoring sites in Palau | Seawater | 90–430 MP $m^{-3}$ | Fragment | Not reported | Beraud et al., 2022 |
| | Sediment and sand | 1,080–71,020 MP $kg^{-1}$ dw | | | |
| Dar es Salaam and Zanzibar Island, Tanzania | Beach sediment | 864.15 ± 275.10 MP $kg^{-1}$ dw | Fragment | PE, PP | Nchimbi et al., 2022 |
| | Seabed sediment | 79.9 ± 21.5 MP $kg^{-1}$ dw | | | |
| Suva, Republic of Fiji | Surface water | 0.14 ± 0.08 MP $m^{-3}$ | Fiber | PE | Ferreira et al., 2020 |
| | Sediment | 19.8 ± 4.2 MP $kg^{-1}$ dw | | | |
| Puerto Rico | Beach sand | 3–17 MP $kg^{-1}$ dw | Fiber | PE | Perez-Alvelo et al., 2020 |
| Naivaru, Maldives | Sediment | 277.90 ± 24.98 MP $kg^{-1}$ dw | Fragment | PS | Patti et al., 2020 |
| Vila Bay and Mele Bay, Vanuatu | Surface seawater | 0.09–0.57 MP $m^{-3}$ | Not reported | PS | Bakir et al., 2020 |
| Port Vila, Vanuatu | Sediment | 833 ± 333 – 19,167 ± 5,085 MP $kg^{-1}$ dw (2017)<br>333 ± 115 – 33,300 ± 7,300 MP $kg^{-1}$ dw (2018) | | | |
| Honiara, Solomon Islands | | 450 ± 180 – 15,167 ± 8661 MP $kg^{-1}$ dw | | | |

Among environmental matrices, sediments consistently registered higher concentrations of microplastics than surface waters and beach sands, validating their role as long-term sinks in nearshore systems (de Smit et al., 2021; Khuyen et al., 2021; Greenshields et al., 2025). The dense and fine-grained nature of sediments promotes the entrapment of fibers and fragments of microplastics to settle increasingly from the water column. High silt and clay fractions in sediments also enhance particle entrapment in near-surface layers, with sandy substrates permitting deep penetration due to diminished packing densities (Greenshields et al., 2025). Turbidity currents with fine sediments transport microplastics long distances, and transport efficiency is amplified with higher sediment concentration (Soler et al., 2025). Even retention also depends on particle shape: fibrous particles tend to be retained in interstitial space regardless of grain size, while fragment retention is more limited by sediment grain diameter, implying that pore-space availability constrains patterns of deposition (Fenn et al., 2025).

Higher tidal kinetic energy enhances microplastic loads in the water column through resuspension of previously settled material from the sediments (Marcus et al., 2023). Water samples thus typically possess lower though more variable concentrations (e.g. 0.09–0.57 MP $m^{-3}$ for Vanuatu and 0.14 ± 0.08 MP $m^{-3}$ for Fiji), illustrating the transitory nature of hydrodynamic energy, resuspension, and tidal flushing enhancing microplastic transport (Jaubet et al., 2021). In parallel, beach sediments registered intermediate values, which were conditioned by periodic deposition of floating litter through wave activity. Organogenic substrates such as Malta's Posidonia oceanica seagrass beds (53.14 MP $m^{-2}$) served as natural traps for suspended plastics, i.e., particles and fibers, evidencing their ecological relevance as Mediterranean coast biofilters. Across island contexts, microplastic assemblages consistently exhibit fragment and fiber predominance, with lower ratios of films, foams, and pellets.

Commonly documented fragment dominance across areas such as Indonesia, Tanzania, and the Maldives, is indicative of persistent degradation of macroplastic refuse, including packaging materials, bottles, and containers. Fibers, particularly abundant in Fiji, Hawai ʻi, and other fishing-intensive islands, are primarily derived from synthetic textiles, fishing lines, and ropes, indicating the strong contribution of maritime activities. The coexistence of multiple morphotypes within single sampling sites underscores the combined influence of terrestrial and marine sources, including coastal runoff, aquaculture, and port operations. Local case studies such as the prevalence of white foam and blue fibers in India's St. Mary's Island better elucidate how site-specific activity affects microplastic morphology and abundance (Khaleel et al., 2023). Polymer composition provides additional information on material persistence and source apportionment.

In the majority of analyses, polyethylene (PE) and polypropylene (PP) are the most prevalent polymers, which is expected due to their broad applications in packages and fishing equipment and low density, which can support buoyant transportation (Praved et al., 2025). Polystyrene (PS), however, predominantly originates from expanded styrofoam products associated with tourist development and food packaging (Chan & Not, 2023). Regular occurrences of pre-production pellets (typically PE) near ports and industrial parks point to localized industrial leakages (Folbert et al., 2025). The relatively consistent polymer profile of numerous island systems speaks to the worldwide ubiquity and environmental robustness of commodity plastics, while polymers and morphologies exhibiting regional variations point to varying socio-economic and activity-borne pollution signatures in small island ecosystems. The discovered sources of microplastics in island systems are divided into three broad groups: land inputs via runoff, urban drainages, and mismanagement of solid wastes (e.g., Indonesia, India); sea sources like loss of fishing gears, aquaculture material, and recreational activities; and ocean transport introducing trash from distant locations (e.g., Hawai'i, Palau).

For example, the decreasing concentration gradient along the Vila Bay to Mele Bay (Vanuatu) suggests widespread land-based inputs that are controlled by local hydrodynamics. Across island systems, sediments consistently function as ultimate sinks of microplastic pollution, typically exhibiting higher concentrations than surface waters and beach matrices, with contamination patterns largely determined by population density, waste-management capacity, and proximity to land-based discharge points. These results provide a crucial empirical foundation for subsequent sections (3.2–3.4), which investigate biological uptake, trophic transfer, and socio-ecological impacts of microplastic pollution in island ecosystems.

### 3.2 Bioaccumulation and trophic transfer

Empirical evidence consistently indicates that microplastic (MP) ingestion occurs at all trophic levels in coastal and small island ecosystems, such as planktonic, benthic, and pelagic communities (Zhang et al., 2023; Alfonso et al., 2024; Lange et al., 2025). Coastal surveys in Thailand revealed an average consumption rate of 0.22 $ind^{-1}$ zooplankton particles (Akkajit et al., 2024), while filter-feeding marine bivalves such as *Perna viridis* of St. Mary's Island accumulated blue fibers and seawater foams (218 $m^{-3}$ particles), which they retained for days (Khaleel et al., 2023). More-trophic animals also carry high MP burdens: in Suva, Fiji, gut MP levels in five commercial species strongly correlated with the degree of sediment contamination (Ferreira et al., 2020), suggesting benthic transfer processes. Similarly, in Biawak Island, Indonesia, MPs were detected in sediments (940–1,710 particles $kg^{-1}$ dw) and in certain feeding guilds. Lutjanidae exhibited the highest ingestion rates (1,344–3,763 particles $kg^{-1}$) and inferred prey-mediated transfer, whereas herbivorous Scaridae exhibited 527–785 particles $kg^{-1}$ due to grazing on biofilm-covered corals (Lewaru et al., 2024). The findings thus confirm that both trophic predation and filter feeding facilitate MP transfer in island reef food webs.

The physicochemical characteristics of MPs, namely particle size, morphology, polymer type, and density, influence their uptake, retention, and subsequent bioaccumulation. Fine particles (<0.5 mm, especially <100 μm) dominate bioavailable fractions, comprising >88 % of total MPs in Fiji and Hawai ʻi (Ferreira et al., 2020; Axworthy et al., 2024), and accounting for most fragments in St. Mary's Island and Maldivian sediments (0.1–0.4 mm range) (Patti et al., 2020; Khaleel et al., 2023). Jagged fragments and fibers are the most commonly ingested MP morphotypes in taxa (Emenike et al., 2023) due to their flexibility and high surface-to-volume ratio, both of which promote entanglement and prolonged retention in gut tissues (Li et al., 2022; Chen et al., 2023; Tarte et al., 2025). Moreover, fibrous particles tend to elicit stronger inflammatory and oxidative stress responses whereas fragments tend to be more associated with mechanical blockage and reduced nutrient assimilation in the gastrointestinal tracts of affected species, such as rockfish (Choi et al., 2024). Polymer density also controls vertical availability: low-density polymers (e.g., PE, PP, polyester) float and are in the pelagic food web available to pelagic feeders (Horton et al., 2024), whereas denser types (e.g., PVC, PET, PS) sink to sediments and form benthic food webs (Phaksopa et al., 2021; Isaac & Kandasubramanian, 2021; Jolaosho et al., 2025).

Field surveys present a complex and sometimes contradictory picture of MP magnification across trophic levels. Some of the findings present greater MP burdens in high-level consumers than low trophic animals, which indicate potential trophic transmission and occasional magnification. For instance, predators such as vent crabs and squat lobsters contained some 14 MPs per animal more than the 2–6 MPs commonly encountered in mussels and snails (Park et al., 2024). This was paralleled by an increase in mean MP abundance incrementally from 0.56 to 4.17 items per organism via sequential trophic levels in marine food webs (Sarker et al., 2022). Size- and species-dependent patterns of accumulation have also been revealed, with higher MP burdens in larger or more omnivorous species such as C. lucidus compared to L. polyactis (Shu et al., 2023; Gao et al., 2024), while open-water megafauna such as baleen whales primarily acquire MPs through prey ingestion (Kahane-Rapport et al., 2022). Isotopic food-web trophic studies frequently, however, cite no discernible trophic-position-dependent MP increase, such as found in Vancouver Island ecosystems (Covernton et al., 2022), and polar studies suggest that MP concentrations remain sufficiently low to prevent measurable magnification (Leistenschneider et al., 2022). Meta-analyses further indicate that while bioaccumulation is observed in single trophic levels, widespread biomagnification in marine food webs is not strongly evidenced (Miller et al., 2020).

Empirical assessments of trophic biomagnification for intact microplastic (MP) particles yield inconsistent outcomes because several biological, physical, and methodological factors act in opposing directions. First, particle size and shape determine bioavailability and retention: small particles (<100 μm) are more readily ingested and can translocate into tissues, whereas larger fragments tend to pass through digestive tracts and are rapidly egested (Covernton et al., 2022; Miller et al., 2020). Second, species-specific physiology matters. Many predators rapidly depurate ingested plastics, so even when trophic transfer occurs the net long-term load in higher trophic levels can remain low (Covernton et al., 2022). Third, ecological traits such as feeding mode and habitat use create heterogeneity: suspension feeders and benthic grazers may accumulate different particle suites than mobile predators, producing inconsistent trophic patterns across systems (Fulfer et al., 2021; Au et al., 2017).

Fourth, environmental dynamics change particle states: biofouling increases density and modifies vertical transport pathways, decoupling where particles are produced from where they enter food webs. Fifth, methodological variation such as inconsistent size cutoffs, variable digestion and contamination controls, and differing tissue vs stomach metrics can reduce comparability and can create apparent contradictions across studies (Leistenschneider et al., 2022; Miller et al., 2020). Finally, spatio-temporal heterogeneity (pulse inputs, episodic storms, local pollution sources) means snapshots often fail to capture chronic transfer dynamics; some field studies report higher absolute MP counts in predators (local biomagnification events), while integrative isotope-based analyses often find no systematic trophic enrichment (Park et al., 2024; Covernton et al., 2022). Together, these interacting mechanisms explain why intact MPs show robust trophic transfer but no universal, system-wide pattern of progressive biomagnification.

Laboratory and mesocosm work clarify mechanistically but never fully eliminate such discrepancies. Experimental models invariably demonstrate trophic transfer and dose-dependent accumulation with diminished growth and feeding efficiency of microplastic-treated planktonic predators (Fulfer et al., 2021). Nevertheless, lab experiments usually make use of concentrations many times higher than in nature, and thus probably overestimate rates of transfer and retention compared to what could happen naturally in the field. Comparative data imply rapid depuration and egestion of ingested particles by top predators to prevent long-term bioaccumulation (Covernton et al., 2022), and methodological inconsistency in particle size categorization and detection reduces cross-study comparability (Miller et al., 2020; Leistenschneider et al., 2022). Generally, available information confirms that MPs have access to marine food webs with ease and may impose greater loads upon certain predators but no general pattern of progressive trophic amplification has been shown.

The human and environmental health impacts of such processes are particularly acute in small island ecosystems where seafood forms the economic and nutritional backbone of community livelihoods. Large microplastic burdens in food species such as Perna viridis and Lutjanidae (Khaleel et al., 2023; Lewaru et al., 2024), and frequent occurrence of particles in commercially valuable mollusks, crustaceans, and coral reef fish indicate a tangible pathway of exposure for coastal communities. Across studies, ingestion of microplastics is consistently reported across trophic compartments, although overall human consumption remains limited relative to other exposure routes (e.g., air or freshwater) (Sun & Wang, 2023). Traditional modes of eating that employ whole fish and unpurified shellfish, however, elevate relative risk. Small, fibrous, low-density polymers are widespread across trophic compartments, underscoring the convergence of ecological persistence and dietary exposure. Collectively, these trends signify that bioaccumulation of microplastics in island food webs is an emerging seafood safety, ecosystem health, and small-island livelihood sustainability issue.

### *3.3 Ecotoxicological and ecosystem effects*

While the 11 studies reviewed quantified microplastic (MP) presence and trophic sequestration in small-island ecosystems, a few reported incidental findings of organismal stress responses such as coral tissue abrasion and reduced feeding activity, and hence further research into sublethal and ecosystem-level impacts discussed in this section was justified. Sublethal MP exposures impose great physiological and behavioural stress on a broad variety of marine taxa, particularly those inhabiting coral reefs and small-island ecosystems. Laboratory and field experiments suggest that MP consumption inhibits feeding efficiency, development, and reproduction through physical blockage and biochemical toxicity. MPs are found to be accumulated inside the gills, hepatopancreas, and gut tissue of bivalves, raising respiratory and excretion levels and lowering energy assimilation for growth and gametogenesis (Jiang et al., 2021; Murano et al., 2023). Systematically, crustaceans such as L. vannamei exhibit inhibitory growth, oxidative stress, and hepatopancreatic damage triggered by increasing MP levels (0.02–1 mg $L^{-1}$), in which impaired swimming performance is correlated with disrupted glycolytic and lipid metabolism (Zeng et al., 2023). MPs ingested via diet provoke hyperactive abnormal behavior and neurotoxicity with distinct neurotransmitter pathway disruption compared to water-suspended MPs (Yu et al., 2022). These findings demonstrate that MPs elicit strong sublethal reactions (e.g. feeding inhibition, metabolic disruption, oxidative stress) that lower personal fitness and possibly overall reduce population resistance in reef and lagoon ecosystems.

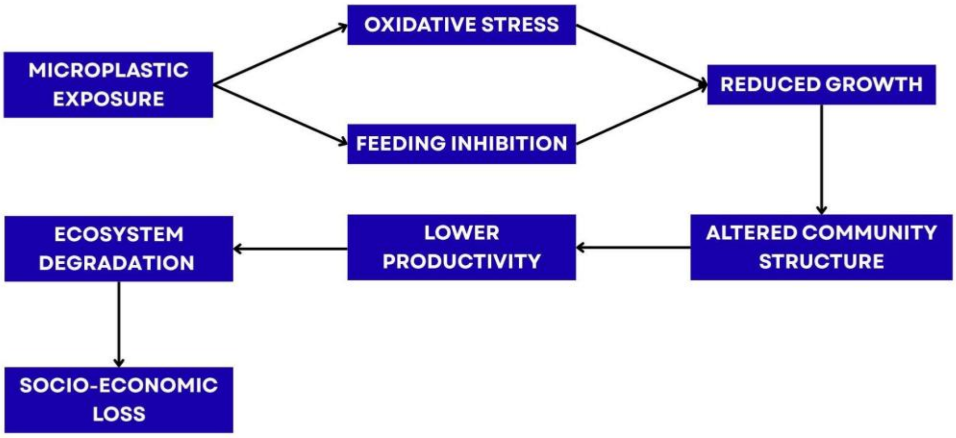


Fig. 1. Conceptual pathway illustrating sublethal and ecosystem-level effects of microplastic exposure in small-island ecosystems

Microplastic exposure provokes oxidative stress in aquatic organisms via multiple, often interacting mechanisms that elevate reactive oxygen species (ROS) production and overwhelm antioxidant defenses. Physically, particles lodged in digestive tissues or gills cause cellular abrasion and damage, triggering localized inflammatory responses that stimulate ROS generation by immune cells as part of the oxidative burst (Jiang et al., 2021). Chemically, MPs frequently carry adsorbed hydrophobic contaminants and leach additives that catalyze redox cycling or disrupt mitochondrial electron transport, both direct sources of intracellular ROS (Jiang et al., 2021; Au et al., 2017). Biofilms (plastispheres) on particles can also harbor pro-oxidant microbial communities that further perturb host redox balance. At the molecular level, elevated ROS (e.g. superoxide anion, hydrogen peroxide, hydroxyl radical) oxidize lipids, proteins, and nucleic acids, producing biomarkers such as increased malondialdehyde (MDA) and protein carbonyls; concomitantly, antioxidant enzymes (superoxide dismutase, catalase, glutathione peroxidase) may be upregulated as a compensatory response, or depleted under chronic exposure leading to oxidative damage (Murano et al., 2023; Zeng et al., 2023). Outcome severity depends on dose, particle size/composition, co-contaminant load, and organismal life stage: juvenile and reproductive tissues often show pronounced sensitivity. Empirical studies in bivalves, crustaceans, and fish document ROS-mediated endpoints—lipid peroxidation, DNA strand breaks, altered energy metabolism—linking particle presence to reduced growth and reproductive capacity (Jiang et al., 2021; Zeng et al., 2023). Thus, ROS generation represents a principal mechanistic pathway translating physical and chemical features of MPs into physiological impairment.

The "plastisphere" refers to the complex microbial biofilms that colonize plastic debris in aquatic environments, transforming inert polymers into biologically active substrates that interact dynamically with host organisms and ecosystems. Plastic surfaces rapidly accumulate conditioning films and subsequently dense microbial assemblages composed of bacteria, microalgae, fungi, and protozoa, with community composition shaped by polymer type, surface roughness, and local environmental conditions (Zettler et al., 2013; Oberbeckmann et al., 2015). These plastisphere communities frequently differ from surrounding seawater microbiota and often enrich opportunistic and pathogenic taxa such as Vibrio spp. and Aeromonas, which increases disease risks when plastics contact sensitive reef organisms. Experimental work has shown that plastic-mediated pathogen transfer can induce severe outcomes such as tissue necrosis in corals, highlighting plastic debris as an emerging vector in marine disease ecology. Ingestion of plastisphere-laden particles can further disrupt gut microbiota (dysbiosis), impair digestive processes, and trigger inflammatory responses in marine turtles and fish, illustrating how microbial shifts extend toxicity beyond the physicochemical impacts of the particles themselves. At broader ecological scales, plastisphere-colonized plastics alter biogeochemical processes by modifying sorption–desorption dynamics of hydrophobic pollutants and enhancing localized heterotrophic activity, thus influencing oxygen exchange and nutrient cycling within microhabitats like coral reefs and mangrove fringes. Collectively, the plastisphere amplifies the ecological risks of microplastic pollution by coupling microbial colonization with contaminant transport and pathogen dispersal, intensifying impacts across biological and ecological levels.

At the community level, persistent MP contamination alters benthic structure, nutrient cycling, and ecosystem productivity in general. Sedimentation on the coastlines of small islands and mangrove mudflats creates permanent plastic sinks that trap organic detritus, inhibit oxygen exchange, and enhance pollution-tolerant organisms (Green et al., 2016). Empirical evidence in lugworm- and bivalve-dominated sediments indicate reduced bioturbation, suppressed microalgal biomass, and shift from oligochaete to polychaete dominance when exposed to MPs (Green et al., 2016; Galloway et al., 2017). In coral reefs, MPs suppress light penetration, interfere with zooxanthellae photosynthesis, and accelerate the rate of coral mortality, decreasing total primary productivity. Modelling experiments forecast these disruptions to reduce photosynthetic efficiency by some 12% and secondary production by up to 7% in heavily impacted regions (Troost et al., 2018). Across experimental and field observations, such findings suggest that chronic MP deposition gradually reduces the ecological resilience of small-island systems, with far-reaching effects on biodiversity and fishery production.

### *3.4 Socio-ecological impacts: Livelihoods, food safety, and equity*

Microplastic (MP) pollution destroys the productivity and market value of small-scale fisheries and aquaculture that sustain many small-island economies. Experimental research links greater organismal MP burdens with reduced growth, degraded condition and reduced reproductive effort—results predicted to be expressed as reduced individual size, reduced catch per unit effort and lower stock productivity in the long term (Jiang et al., 2021; Kibria, 2023; Zeng et al., 2023). Field survey in small-island environments indicates that such locations as mangrove-impaired nursery and fishing grounds have significantly high sediment microplastic levels (Lewaru et al., 2024), toward the indication that native fishing communities working in such locations are exposed to concomitant ecological deterioration alongside economic decline. Market impacts trail environmental degradation: dirty catches may suffer price penalties or local boycotts as consumers detect lower quality (Rivera-Garibay et al., 2024), with the dual effect of smaller catches and low income for small-scale fishers and aqua farmers.

Microplastics found in locally harvested seafood provide a physical pathway for human exposure and pose reasonable threats to food safety and nutritional security. Surveys document frequent detection of MPs in a broad range of edible species (e.g., molluscs, crustaceans, reef fish and some seaweeds), examples being edible macroalgae containing on the order of 10 particles $g^{-1}$ and crab/reef-fish gut burdens in items per gram (Lewaru et al., 2024; Lin et al., 2024). Traditional consumption habits in the form of whole small fish or unpurged shellfish increase probable consumption. Even while the direct causality between MP dietary consumption and human disease is not settled, copresence with bound toxins and microbes creates precautionary concern for groups that consume high levels of seafood as a primary source of protein (Barboza et al., 2018; Kibria, 2023). Generally, MP contamination threatens both the amount and the perceived and actual quality of seafood that constitutes the center of island diets.

Microplastic contamination intersects directly with the livelihoods and food security of small-scale fishers and aquaculture operators, creating both ecological and economic vulnerabilities. Ecologically, MPs reduce individual organism condition via impaired feeding, growth suppression, and reproductive deficits observed in cultured and wild species—effects that can reduce yield per unit effort and growth rates in both capture fisheries and farmed stocks (Jiang et al., 2021; Zeng et al., 2023). Economically, contaminated catches can suffer market penalties: consumer concerns over quality may depress prices, reduce market access (especially export markets with strict safety standards), and force reliance on lower-value local sales (Kibria, 2023; Rivera-Garibay et al., 2024). For aquaculture, MPs enter systems via feed, intake water, and degradation of netting and gear; chronic exposure raises production costs (health interventions, slowed growth), and necessitates investment in filtration or feed screening—capital that small producers often cannot afford (Iheanacho et al., 2023; Miao et al., 2023). Socially, impacts are regressive: low-income households and subsistence fishers who consume whole small fish or local shellfish face higher dietary exposure and fewer alternatives, compounding nutrition and health risks. Adaptive capacity is limited in many small island contexts by weak waste management, scarce monitoring, and narrow economic bases, so shocks to fisheries revenues can cascade into household insecurity. Policy responses that protect these stakeholders include affordable monitoring (citizen science + low-cost assays), targeted upgrades to aquaculture intake and feed standards, market incentives for low-MP products, and waste-management interventions that reduce source leakage—measures that must be socially equitable to avoid further marginalizing vulnerable fishing communities.

MP loads fall disproportionately on island populations with existing social and environmental disparities. Ports and tourist areas, together with high-density coastal villages, concentrate waste inputs and consequently MP loads, while lower-income and more remote villages often lack waste-management facilities to control local leakage (e.g., comparative per-capita waste between tourist and settled islands; above-noted case studies). Thus, low-income fishers and households depending on low-value local seafood bear the disproportionate economic cost (lower value of catch, denial of access to markets) and potential health cost (greater diet exposure) of contamination (Bennett et al., 2023; Karasik et al., 2023). These distributional links identify an environmental-justice dimension of plastic pollution in the ocean: the most irresponsible parties in global plastic streams have the greatest localized impacts.

With these socio-ecological consequences in mind, there are priority actions for monitoring and research. First, targeted measurements must be taken to quantify MPs in consumable tissue (not merely guts) and translate observed levels to estimates of dietary exposure that are matched to regional diets. Second, longitudinal socio-economic research must correlate ecological metrics (condition, growth, recruitment) with fishery landings and market revenues. Third, spatially resolved monitoring that overlays hotspots of contamination with measures of community dependence would identify the most vulnerable populations and inform equitable interventions. Closing these gaps—through harmonized analytical tools and participatory sampling—will be required to assess the true extent of food-safety risks, forecast long-term livelihood impacts, and design interventions that protect ecological integrity and social welfare in small-island settings.

### *3.5 Methodological heterogeneity and implications for interpretation*

An additional source of uncertainty arises from inconsistent use of key conceptual terms across the literature. Ingestion refers to the intake of microplastic particles by an organism but does not imply retention, whereas bioaccumulation describes persistence resulting from the balance between ingestion and elimination, and biomagnification denotes increasing contaminant burdens across trophic levels. Many studies quantify microplastics in gastrointestinal contents and report ingestion rates without assessing tissue retention or trophic enrichment. Consequently, ingestion metrics are often interpreted as evidence of bioaccumulation or biomagnification despite the absence of longitudinal or food-web–resolved data, contributing to mixed conclusions on trophic transfer and highlighting the need for clearer terminological distinctions.

Interpretation of microplastic (MP) distribution, bioaccumulation, and socio-ecological impacts in small-island ecosystems is further constrained by methodological heterogeneity across studies. Particle size thresholds and identification methods vary widely, directly influencing reported abundance and polymer composition. Comparability is also limited because studies examine different matrices—water, sediments, gastrointestinal contents, or edible tissues—and report results using inconsistent units, complicating cross-system synthesis. Such differences strongly influence conclusions regarding trophic processes, since apparent bioaccumulation or biomagnification patterns depend on particle size, tissue compartment analyzed, and detection limits.

Uncertainty is further amplified by spatial and temporal biases, as data remain concentrated in a limited number of island systems and often rely on short sampling windows that fail to capture long-term accumulation dynamics. These limitations hinder robust inference regarding chronic exposure and socio-ecological impacts, while the absence of harmonized protocols obscures distinctions between ingestion, short-term accumulation, and true trophic magnification. Addressing these gaps will require standardized reporting metrics, consistent analytical validation, and integrated monitoring linking environmental matrices, biological compartments, and human-relevant endpoints to support more reliable risk assessment and mitigation planning in small-island socio-ecological systems.

## 4. Conclusions

Microplastic pollution in small-island ecosystems constitutes a multi-scalar socio-ecological crisis that links environmental degradation with community vulnerability. Synthesized evidence reveals that island and coastal systems act as both conduits and long-term sinks for microplastics, with sediments showing the highest accumulation due to weak hydrodynamics and inadequate waste management. These plastics impose widespread sublethal stress on marine organisms, including feeding inhibition, oxidative damage, and impaired reproduction, while facilitating pathogen and contaminant transfer through biofilm formation. Such disruptions degrade coral, mangrove, and seagrass ecosystems, undermining biodiversity, fisheries productivity, and coastal protection. The resulting socio-economic consequences are profound: reduced catch yields, lower seafood quality, and diminished market value directly threaten food security and livelihoods in small-island communities, where exposure and adaptive capacity are unequally distributed.

However, substantial uncertainty remains due to methodological inconsistencies, uneven geographic coverage, and limited long-term monitoring, constraining robust comparison across island systems and complicating risk assessment. Addressing these challenges requires prioritizing mitigation strategies that are feasible in small-island contexts, including improved local waste-management systems, low-cost monitoring and community-based surveillance, reduction of land-based plastic leakage, and targeted support for fisheries and aquaculture sectors most vulnerable to contamination. Strengthening standardized monitoring and integrating ecological and socio-economic assessments will be essential for translating scientific evidence into equitable and effective interventions, positioning microplastic pollution not only as an ecological issue but also as a matter of environmental justice requiring coordinated scientific, policy, and community action.


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No new data were created or analyzed in this study. Data sharing is not applicable to this article.

## Conflicts of Interest

The author declares no conflict of interest.

### Declaration of Generative AI Use

During the preparation of this work, the author used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the content of the publication.

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