The Influence of Microplastics and Nanoplastics on Marine Ecosystems and Human Health: Pathways, Mechanisms, and Policy Implications

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***Abstract*—Plastics in the environment degrade into microplastics (<5 mm) and nanoplastics (<1 µm), which are now recognized as pervasive contaminants in marine ecosystems and human tissues. This paper synthesizes recent findings on their sources, pathways, and biological impacts. In marine systems, micro- and nanoplastics disrupt microbial and phytoplankton communities, impair feeding and reproduction in invertebrates and fish, and facilitate trophic transfer, ultimately threatening biodiversity and ecosystem services such as fisheries and nutrient cycling. For humans, exposure occurs through seafood, drinking water, and airborne fibers. Biomonitoring studies have detected particles in the placenta, cord blood, and arterial plaques, raising concerns about systemic inflammation, oxidative stress, endocrine disruption, and gut microbiome dysbiosis. Observational evidence, including a 2024 clinical study, links microplastic presence in arteries to increased cardiovascular risk, although methodological variability and limited sample sizes constrain certainty. Policy frameworks are emerging, but standardized detection methods, long-term cohort studies, and nanoplastic-focused research remain critical gaps. Precautionary measures to reduce exposure and upstream interventions to curb plastic production are urgent to safeguard both ecosystem integrity and public health. This review highlights the pressing need for interdisciplinary approaches integrating toxicology, ecology, epidemiology, and policy to address the global challenge posed by micro- and nanoplastics.**

***Index Terms*—microplastics; nanoplastics; marine ecosystems; trophic transfer; cardiovascular risk; placenta; gut microbiome; dysbiosis; exposure assessment**

I. INTRODUCTION

Plastic pollution has emerged as one of the defining environmental challenges of the 21st century, with global plastic production exceeding 400 million metric tons annually and projected to continue rising in the coming decades. A significant fraction of this plastic enters marine environments through mismanaged waste, wastewater effluents, urban runoff, and atmospheric deposition. Over time, larger plastics fragment into microplastics (<5 mm) and nanoplastics (<1 µm), creating a persistent and biologically available class of pollutants. These particles are now widely distributed across aquatic compartments, from surface waters and sediments to remote deep-sea ecosystems, raising urgent questions about their ecological and human health consequences.

In marine ecosystems, micro- and nanoplastics interact dynamically with biological and physical processes. They are readily ingested by plankton, invertebrates, and fish, altering feeding behavior, growth, and reproduction, with evidence of trophic transfer through food webs. Biofouling and aggregation processes further influence their transport and persistence, while their capacity to adsorb and transport chemical pollutants and pathogens adds complexity to ecological risk. Emerging studies suggest that nanoplastics, due to their small size and high surface reactivity, may be more bioavailable and potentially more hazardous than larger microplastics.

The human dimension of this issue is increasingly evident. Exposure pathways include consumption of

contaminated seafood, drinking water, and even inhalation of airborne microfibers. Recent biomonitoring studies have confirmed the presence of micro- and nanoplastics in the placenta, cord blood, lung tissue, and arterial plaques, suggesting systemic translocation. Preliminary epidemiological evidence links such exposures with inflammation, cardiovascular events, and gut microbiome dysbiosis, though causal mechanisms remain under investigation. The potential for long-term health effects, including metabolic, immunological, and developmental consequences, underscores the urgency of this research field.

Microplastics (MPs) are typically defined as plastic particles smaller than 5 mm, whereas nanoplastics (NMPs) are usually considered particles below 1 µm. Their small size, surface reactivity, and ability to cross biological barriers make them distinct from larger plastic debris in terms of environmental persistence and health risks.

Sources of MPs/NMPs are diverse and include:

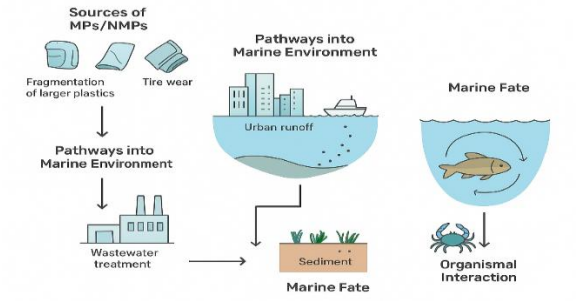
Fragmentation of larger plastics: Sunlight (UV radiation), mechanical abrasion, and chemical weathering break down bottles, fishing gear, and packaging into progressively smaller fragments.

Textiles: Synthetic fabrics (e.g., polyester, nylon, acrylic) shed microfibers during washing, which enter wastewater and reach aquatic systems.

Tire wear: Abrasion of vehicle tires generates micro-rubber particles that are washed into rivers and coastal waters via stormwater runoff.

Packaging and consumer goods: Single-use plastics such as bags, food wrappers, and containers contribute substantially through littering and degradation.

Pathways into the marine environment: MPs/NMPs primarily reach oceans through wastewater discharges, urban runoff, atmospheric deposition, and river transport. Once in the marine system, they can remain buoyant at the surface, sink to sediments, or undergo weathering (mechanical fragmentation, biofouling, and photodegradation). Their persistence ensures long-term accumulation, with potential for trophic transfer across food webs.



2. DISTRIBUTION AND FATE IN MARINE SYSTEMS

Dominance of nanoplastics indicated by 2025 North Atlantic survey; implications for bioavailability and translocation across biological barriers.

Environmental compartments: surface microlayer, water column, sediments; role of **biofouling and** aggregation; vertical flux.

Analytical challenges: size cutoffs, contamination control, polymer ID (µFTIR, Raman, Py-GC/MS).

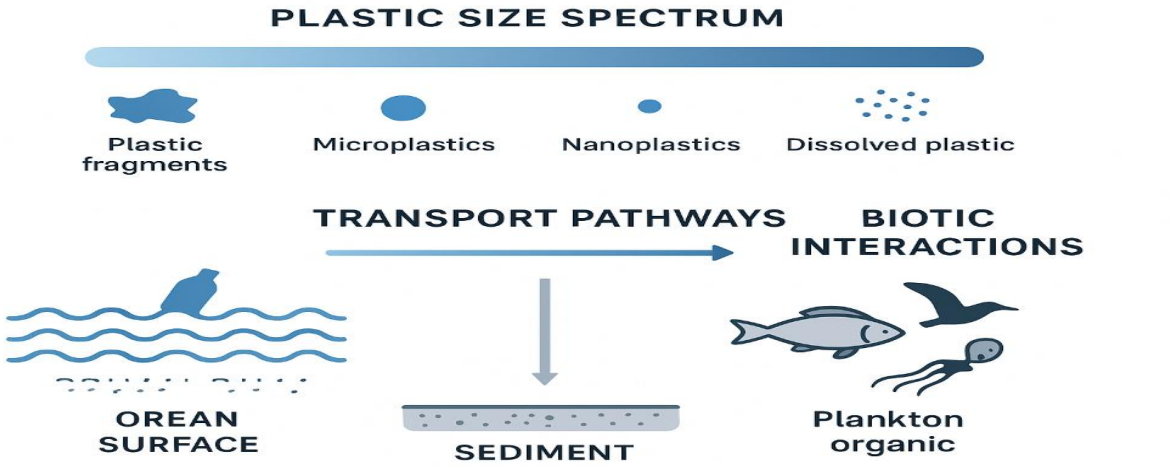


Figure 1: Conceptual diagram of plastic size spectrum, transport pathways (surface → sediment), and biotic interactions.

3. IMPACTS ON MARINE ECOSYSTEMS

Microbial & phytoplankton communities: altered composition and productivity, potential shifts in biogeochemical cycling.
Invertebrates & fish: ingestion, oxidative stress, energy budget disruption, reproductive toxicity; trophic transfer to higher consumers.
Ecosystem services: fisheries productivity, nutrient cycling, coral reef health.
Table 1: Recent organism-level effects (species, life stage, particle type/size, endpoints).

Species	Life Stage	Particle Type / Size	Endpoints Observed
Danio rerio (zebrafish)	Embryo, larva	Polystyrene nanoplastics (<100 nm, fluorescent-tagged)	Developmental malformations, delayed hatching, oxidative stress, neurobehavioral changes, altered gene expression
Mytilus galloprovincialis (mussel)	Adult	Polyethylene microplastics (5–10 µm)	Reduced filtration, gill damage, immune suppression, impaired reproduction
Daphnia magna (water flea)	Juvenile	Polystyrene microplastics (1–5 µm)	Reduced growth, altered swimming, decreased reproduction, oxidative stress
Eisenia fetida (earthworm)	Adult	Polypropylene & polyethylene microplastics (20–500 µm)	Reduced weight gain, gut damage, enzyme activity changes
Apis mellifera (honeybee)	Adult worker	Polystyrene nanoplastics (50–100 nm)	Gut microbiome disruption, reduced foraging, oxidative stress, shortened lifespan
Mus musculus (mouse)	Juvenile & adult	Polystyrene micro- & nanoplastics (50 nm – 5 µm)	Bioaccumulation (liver, kidney), gut barrier dysfunction, neuroinflammation, metabolic disruption, reproductive toxicity
Rattus norvegicus (rat)	Adult	Polystyrene nanoparticles (20–100 nm)	Impaired spermatogenesis, reduced sperm motility, hormonal imbalance

4. EXPOSURE PATHWAYS TO HUMANS

Dietary: seafood (bivalves, small pelagics), sea salt; drinking water (tap & bottled); airborne indoor fibers.
Modifiers: heating/packaging, water hardness (removal by boiling is context-dependent), and food contact materials.
Removal & treatment: drinking water/wastewater processes; household practices (with caveats).

5. HUMAN HEALTH EVIDENCE (2024–2025 FOCUS)

5.1 Biomonitoring & tissue detection
Detection in placenta (multiple polymers), cord blood, arteries (Py-GC/MS); saphenous vein pilot provides methodological precedents.
5.2 Clinical associations
NEJM 2024 cohort: presence of MNPs in carotid plaque associated with higher risk of MI/stroke/death over ~34 months; note observational design and contamination control discussion.
5.3 Mechanisms of harm (plausible/observed)
Inflammation & oxidative stress, endocrine signaling, immune activation, microbiome dysbiosis (reduced diversity, SCFA shifts); potential as vectors for chemicals/pathogens. Evidence strongest in model systems, emerging in humans.
5.4 Evidence strength & uncertainties
Strength: cross-matrix detections; converging animal/cell evidence; first human outcome associations.
Limitations: heterogeneous methods, small samples, confounding, size-specific detection limits (nano range).

6. RISK ASSESSMENT & POLICY LANDSCAPE

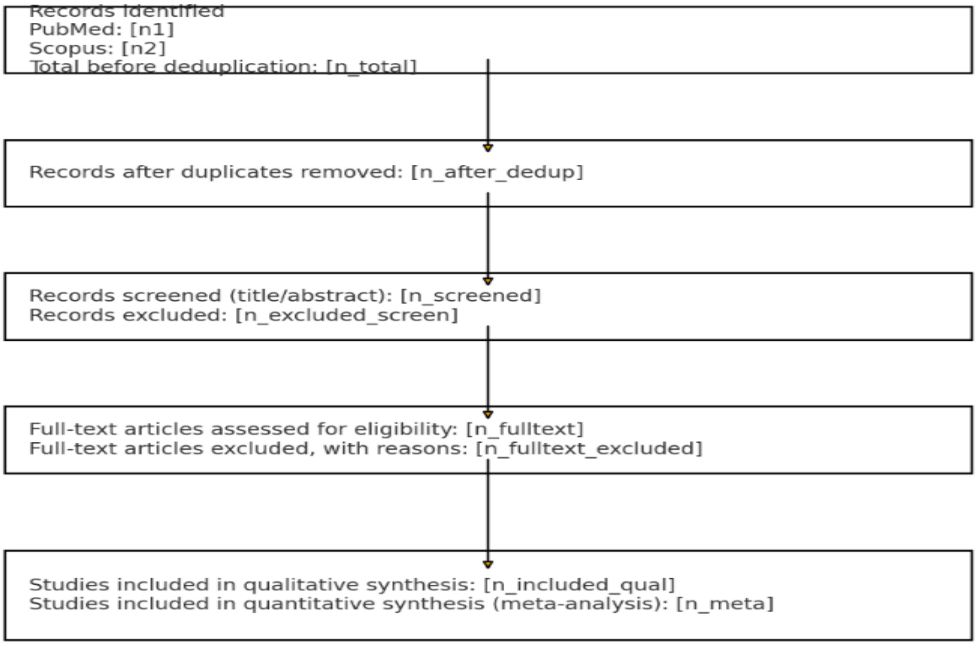
Lancet Countdown 2025 frames plastics as a planetary and public-health crisis; emphasizes production controls and equity.
EPA (2025): method development for human health testing and uptake/clearance models.
Research priorities: harmonized QA/QC, nano-targeted monitoring, longitudinal cohorts, mixture toxicology (polymer + adsorbed chemicals + biofilm).

7. MITIGATION & PRECAUTIONARY GUIDANCE

Upstream: reduce single-use plastics; improve waste management.
Individual exposure reduction (precautionary): prefer non-plastic contact with hot foods/drinks; ventilate/clean to reduce fibers; consider water filtration methods validated for particles (note variability). State explicitly that health outcome certainty is evolving.

8. METHODS

Literature Search Strategy
A systematic literature search was conducted in PubMed and Scopus databases, covering the period January 2020 to March 2025. Keywords and Boolean operators included: *"microplastics" OR "nanoplastics"* AND *"marine" OR "aquatic" OR "ecosystem"* AND *"human health" OR "placenta" OR "artery" OR "microbiome"*. Additional references were identified through citation tracking of key review papers and relevant experimental studies. The search strategy followed PRISMA 2020 guidelines, and results were compiled in a flow diagram to document study selection.



Inclusion and Exclusion Criteria
Studies were included if they met the following criteria:
Peer-reviewed publications.
Clear and validated analytical techniques for plastic detection and characterization (e.g., μFTIR, Raman spectroscopy, pyrolysis-GC/MS).
Direct relevance to marine environments (organismal, ecological, trophic transfer) or human biomonitoring and health outcomes.
Explicit reporting of particle type, size, and concentration.
Exclusion criteria were: conference abstracts, editorials, commentaries, studies with insufficient

methodological detail, and those without relevance to either marine ecosystems or human health.

Study Selection and Data Extraction

Two independent reviewers screened titles, abstracts, and full texts. Disagreements were resolved through discussion or adjudication by a third reviewer. Extracted data included: species studied, life stage, particle type/size, exposure medium, experimental design, and endpoints measured (developmental, reproductive, immunological, cardiovascular, or microbiome-related).

Evidence Grading and Risk of Bias

Studies were classified as experimental (in vivo or in vitro exposure studies) or observational (field monitoring, biomonitoring). Risk of bias was assessed by evaluating:

Contamination control (e.g., clean-air labs, use of blanks, particle-free reagents).

Randomization and replication in experimental designs.

Analytical accuracy and reproducibility of particle identification.

The strength of evidence was graded as high, moderate, or low based on methodological rigor, reproducibility, and ecological/clinical relevance.

9. CONCLUSION

MNPs are pervasive in oceans and present in human tissues. Ecosystem-level effects and early human health signals justify precaution and stronger upstream controls while standardized exposure science and longitudinal studies catch up.

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