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Polymer composition of microplastics in marine organisms across trophic levels

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Abstract. Microplastic contamination poses a growing threat to marine ecosystems and human health, with impacts observed across all trophic levels. This study reviews 16 empirical articles to extract data on the chemical composition and morphological features of microplastic particles found in marine organisms. The analysis focuses on herbivorous, omnivorous, and carnivorous taxa, emphasizing polymer diversity and accumulation patterns. Polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) were the most commonly detected polymers across all trophic levels, with fiber as the dominant morphological form. Polymer diversity tended to increase in higher trophic levels, suggesting potential bioaccumulation. The color and shape of particles further varied across species, with blue and black fibers being the most frequent. The findings underline the need for consistent reporting of polymer data and reinforce the importance of integrating chemical composition analysis in microplastic monitoring strategies.

1 Introduction

Microplastic (MP) contamination has been widely acknowledged as a pervasive pollutant in aquatic ecosystems [1]. These particles, defined as plastic fragments between 1 µm and 5 mm in size, originate from both primary sources, such as personal care products, and secondary sources, including the fragmentation of larger plastics [2]. They are capable of entering marine environments through multiple routes, including sewage discharge, riverine inputs, fishery activities, and urban runoff [3]. Once present in the ocean, MPs interact with a wide range of organisms, from planktonic filter feeders to large predatory fish [4]. Due to their small size and durability, MPs are readily ingested by marine organisms, leading to trophic transfer and potential bioaccumulation [5].

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The chemical composition of MPs, particularly their polymer types, plays a critical role in their environmental behavior and biological impact. Polymers such as polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) dominate marine MP contaminants due to their widespread usage and resistance to degradation [6]. These polymers originate largely from packaging materials, synthetic textiles, fishing gear, and household products [7]. The capacity of these polymers to persist in seawater and resist biological decomposition makes them ideal candidates for long-term environmental accumulation [8]. Identifying and comparing polymer composition among various marine species across trophic levels offers insights into contamination pathways and the risks associated with microplastic ingestion [9].

Studies focusing on MP contamination have traditionally reported abundance values, particle sizes, and ingestion rates, often neglecting the chemical diversity of polymer types [10]. However, the nature of the polymer, including its density, chemical inertness, and structural integrity, affects not only its environmental mobility but also its tendency to accumulate in different trophic levels [11]. Herbivorous organisms typically ingest MPs directly from sediment or suspended particulates [12], while omnivores and carnivores may accumulate MPs indirectly through prey consumption [13]. These differences in feeding behavior and ecological roles may result in variations in polymer profiles, particle morphologies, and levels of contamination [14].

In this paper, we focus on synthesizing information on the chemical properties and distribution of microplastic polymers across different marine trophic levels. We draw from 16 peer-reviewed empirical studies that investigated microplastic contamination in marine organisms. These include herbivores such as *Diadema africanum* [14], omnivores such as *Squalius vardarensis* [15], and carnivores such as *Thunnus thynnus* [16]. We analyze reported patterns in polymer types [14][15][16], particle morphologies [15][16], and potential contamination sources [14][15]. We aim to clarify how polymer composition varies between herbivorous, omnivorous, and carnivorous organisms and to identify consistent patterns that may inform future monitoring and mitigation strategies.

2 Materials and methods

2.1 Literature selection

This study is based on a synthesis of 16 empirical studies that specifically investigated microplastic contamination in marine organisms across different trophic levels, with a focus on chemical polymer composition and particle morphology. The selected references include herbivorous species such as *Diadema africanum* [14], *Siganus* spp. [17], and *Lymnaea stagnalis* [18]; omnivores such as *Squalius vardarensis* [15], *Engraulis encrasicolus* and *Sardina pilchardus* [19], *Eriocheir sinensis* and *Carcinus maenas* [20]; and carnivores such as *Thunnus thynnus* [16], *Trichiurus lepturus* [20], *Comber colias* [19], *Salmo trutta* [13], and mesozooplanktons [21]. The additional studies used combined trophic categories or offered broader trophic comparisons, including [22], [23], [24], [25], and [26]. These 16 references ([6], [12], [13], [14], [15], [16], [17], [18], [20], [21], [22], [23], [24], [25], and [27]) form the core dataset for this review and were selected based on their provision of original, empirical data on both polymer identity and particle characterization.

2.2 Data extraction

The 16 peer-reviewed articles systematically analyzed in this study were selected based on their direct relevance to microplastic ingestion and polymer composition in marine species. Each study provided original quantitative data on polymer types, concentrations, particle morphologies, or spatial occurrence of microplastics in the gastrointestinal tracts or tissues of marine organisms. For each article, we extracted detailed metadata including trophic category, species identity, sampling location, analytical techniques (e.g., FT-IR or Raman microspectroscopy), microplastic concentrations (expressed in items per individual or per gram), particle morphologies (e.g., fiber, fragment, film), and polymer types (e.g., PE, PP, PET). The articles were reviewed to ensure consistency in data reporting and compatibility for comparative analyses across trophic levels.

2.3 Data organization and comparative analysis

All extracted data were organized into a structured matrix grouped by trophic category: herbivores, omnivores, and carnivores. Each entry included quantitative measures of microplastic abundance, qualitative descriptions of polymer diversity, and details on particle morphology and coloration. This structure enabled direct comparison of polymer profiles and contamination levels across trophic strategies. Comparative analysis focused on identifying trends in polymer type distribution, with particular attention to frequently reported polymers such as polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET). We also assessed patterns in particle morphology (e.g., prevalence of fibers over fragments), polymer diversity within trophic groups, and potential associations between trophic level and microplastic characteristics. Studies using Raman microspectroscopy or FT-IR were analyzed with equal weight, and differences in analytical resolution were noted where relevant but not used to exclude any dataset.

Microplastics are plastic particles smaller than 5 mm in size and are composed of various synthetic polymers such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC). Each polymer type typically reflects its original plastic source; for example, PE and PP are commonly derived from packaging materials and plastic bags, while PET is often found in beverage bottles and textile fibres. The physical properties of these polymers, especially their density, strongly influence their distribution in aquatic environments: low-density polymers like PE and PP tend to float, while denser polymers such as PET and PVC are more likely to sink. Microplastics are also classified by their morphological forms, including films (thin sheets), fragments (broken pieces), foams (porous plastics like styrofoam), and pellets (small plastic granules), which indicate either the degradation pattern or the original form of the plastic product. The images below illustrate common microplastic morphologies found in aquatic environments (Figure 1). These morphological types often correlate with specific polymers; for instance, films are typically made from polyethylene or polypropylene, foams are commonly polystyrene-based, and pellets are usually composed of PE or PP as industrial raw materials.

3 Results and discussion

3.1 Microplastics morphology

Microplastics are plastic particles smaller than 5 mm in size and are composed of various synthetic polymers such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC). Each polymer type typically reflects its original plastic source; for example, PE and PP are commonly derived from packaging materials and plastic bags, while PET is often found in beverage bottles and textile fibers. The physical properties of these polymers, especially their density, strongly influence their distribution in aquatic environments: low-density polymers like PE and PP tend to float, while denser polymers such as PET and PVC are more likely to sink. Microplastics are also classified by their morphological forms, including films (thin sheets), fragments (broken pieces), foams (porous plastics like styrofoam), and pellets (small plastic granules). Common microplastic morphologies found in aquatic environments are depicted in Figure 1. These morphological types often correlate with specific polymers; for instance, films are typically made from polyethylene or polypropylene, foams are commonly polystyrene-based, and pellets are usually composed of PE or PP as industrial raw materials.

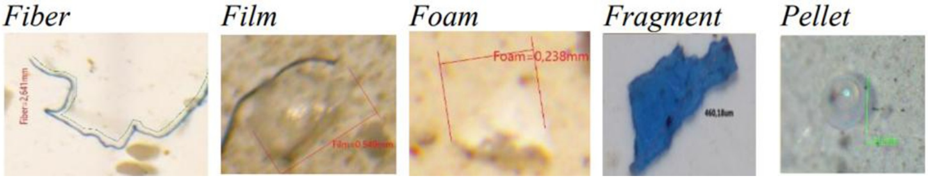

Fig.1. Examples of morphological types of microplastics observed in environmental samples. (A) Fiber – long and thread-like, typically originating from textiles or ropes. (B) Film – thin plastic sheeting, often from packaging or degraded bags. (C) Foam – a cellular plastic structure from materials such as polystyrene. (D) Fragment – irregularly shaped piece broken off from larger plastic objects. (E) Pellet – a rounded pre-production plastic resin bead. All images captured via microscopy (Modified from [28][29][30].)

3.2 Polymer diversity and microplastics morphology across trophic levels

The analysis of 16 empirical studies confirms that polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) are the most frequently detected microplastic polymers in marine organisms across all trophic levels, as seen in Figure 2. These three polymers were identified in over half of the reviewed studies and appeared consistently in herbivorous, omnivorous, and carnivorous taxa. Their dominance reflects widespread usage in packaging, fishing gear, and textiles, as well as their persistence and buoyancy in marine environments [6][7][31], besides also suggests a high prevalence and exposure of these polymer types within marine ecosystems. Moreover, the consistent appearance of PE and PP in studies involving all three trophic levels (carnivores, omnivores, and herbivores) may be attributed to their global production volumes and widespread environmental presence, owing to their lightweight and durable physicochemical properties. In contrast, polymers such as nylon (PA), polyurethane (PU), and polyvinyl chloride (PVC) are less frequently studied, particularly in herbivorous and omnivorous organisms. This may reflect variations in polymer characteristics that influence their environmental distribution, or differences in the ability of organisms to accumulate or ingest specific polymers. These findings provide an initial indication of potential links between feeding strategies and the types of microplastics accumulated in marine biota.

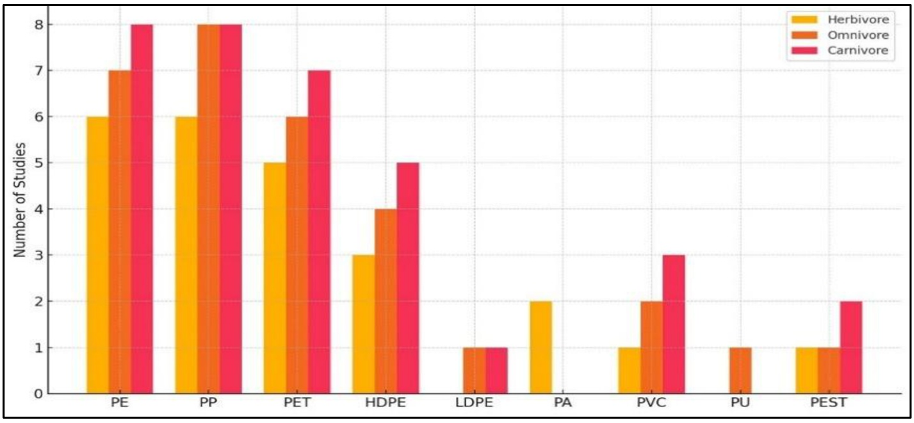

Fig. 2. Frequency of polymer types across different trophic levels.
The chart summarizes the number of reviewed studies (n = 16) reporting each polymer type: polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyamide (PA), polyvinyl chloride (PVC), polyurethane (PU), and polyesters (PEST) in herbivorous, omnivorous, and carnivorous species. Counts reflect synthesis of reported occurrence patterns.

As also shown in Figure 2, PE and PP were each reported in eight separate studies involving carnivorous species and appeared with similarly high frequency in omnivorous and herbivorous groups. PET was also frequently detected, particularly in herbivores and omnivores, suggesting a strong link to textile-derived microfibers and wastewater runoff. The ubiquity of these polymers across trophic groups supports the conclusion that environmental exposure to these materials is widespread and not restricted to any one ecological niche. Because these polymers are hydrophobic and chemically stable, they also tend to sorb environmental contaminants, which further increases their ecological impact [31].

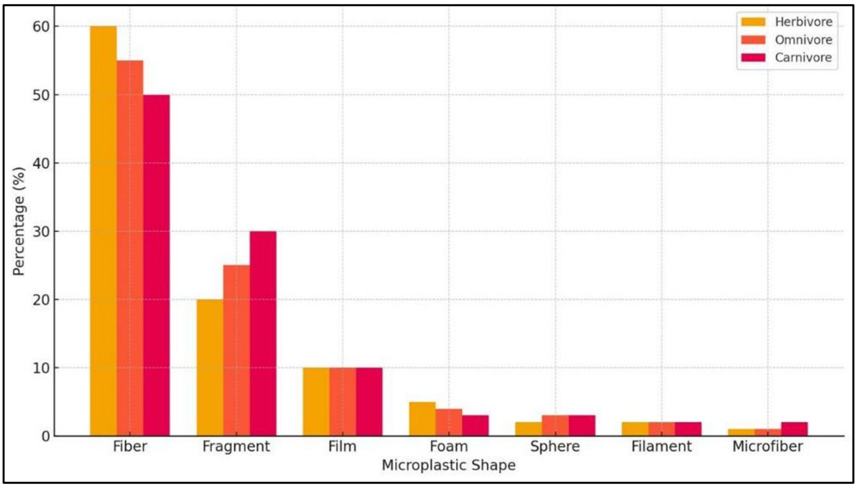

Fig. 3. Percentage distribution of microplastic shapes detected in marine organisms across different trophic levels.
Fibers were the dominant shape across all groups, particularly among herbivores. Fragments and films were more common in omnivores and carnivores. This visual summary emphasizes morphological

characteristics of ingested microplastics by trophic strategy and complements polymer composition analyses (Figure 2), offering an accessible overview for comparative interpretation. Counts reflect synthesis of reported occurrence patterns. Morphological characteristics of microplastics, such as their shapes and forms, which may influence their ingestion, retention, and transfer within marine food webs. Moreover, the relationship between polymer types and the morphology of microplastics has been widely acknowledged, as certain polymers tend to degrade into specific physical shapes depending on their original use and environmental exposure.

Figure 3 illustrates the distribution of microplastic shapes found across different trophic levels in marine organisms, such as herbivores, omnivores, and carnivores. The data reveal a clear dominance of *fibers* across all trophic groups, with herbivores exhibiting the highest proportion (～60%), followed by omnivores (～55%) and carnivores (～50%). This suggests that fibrous microplastics, often originating from textiles and fishing gear, are highly prevalent and likely to be ingested by a broad range of marine species regardless of their dietary habits. *Fragments* represent the second most common shape type, with a gradual increase in proportion from herbivores to carnivores, possibly indicating that higher trophic levels ingest microplastics indirectly through trophic transfer. Shapes such as *films*, *foams*, *spheres*, *filaments*, and *microfibers* were present in much lower percentages but show a relatively consistent pattern across trophic groups.

3.3 Variations in polymer diversity by feeding group

In addition to identifying the most common polymers, the reviewed literature revealed patterns in polymer diversity associated with trophic level. Carnivorous species exhibited the highest diversity of detected polymers, with eight distinct polymer types reported across multiple studies. These included not only PE, PP, and PET, but also HDPE, PVC, PEST, and in some cases LDPE and PU. For example, polymers in *Thunnus thynnus* and *Trichiurus lepturus* extended beyond the common packaging-related plastics, indicating accumulation from diverse prey sources and broader environmental pathways [21][6].

Omnivorous species demonstrated moderate polymer diversity. In addition to the three dominant polymers, studies on species such as *Engraulis encrasicolus* and *Carcinus maenas* reported the presence of PVC and LDPE [19][20]. The broader polymer spectrum observed in omnivores likely results from their mixed feeding strategies, which include direct ingestion of sediments as well as predation on smaller, contaminated species. In contrast, herbivorous species were associated with a more restricted polymer profile. Most studies on herbivores such as *Siganus* spp., *Diadema africanum*, and *Lymnaea stagnalis* reported only PE, PP, and PET, with minimal reports of heavier or industrial-use polymers such as PVC or PU [17][14][18]. These organisms typically feed directly on benthic substrates or suspended particulates, which may limit their exposure to complex synthetic materials that tend to accumulate through marine food webs. The observed trend of increasing polymer diversity with trophic level supports the hypothesis of trophic transfer. Carnivores, which occupy higher positions in the food web, are more likely to ingest plastics not only from their environment but also from their prey. While more research is needed to quantify bioaccumulation directly, this diversity pattern aligns with known pathways of contamination in aquatic food chains [5][13].

3.4 Environmental sources and toxicological relevance

The identity of detected polymers also provides insight into the sources and associated risks of microplastic contamination. PE and PP are commonly derived from consumer packaging, fishing lines, and disposable plastics. PET is associated with textile fibers and urban wastewater effluents [3][7][24]. Their widespread detection suggests that most marine organisms are exposed to common synthetic materials introduced through both coastal urban runoff and long-range transport. The presence of HDPE and LDPE in several carnivorous and omnivorous species suggests exposure to more durable plastics, including those from containers, household goods, and industrial items. Polymers such as PU, PA, and PEST were less frequent but appeared primarily in carnivores. These are associated with high-end materials such as foams, synthetic coatings, and structural textiles. Their detection may point to urban-industrial sources and wastewater pathways that are not typically associated with shoreline litter [23][26][32]. Polymer composition has toxicological significance because different polymers interact with the environment in different ways. PE and PP are known to sorb persistent organic pollutants such as PAHs and PCBs. PET, particularly in its fiber form, can retain metal ions and synthetic dyes [31][33]. Studies on animal models have shown that ingestion of these microplastics can cause changes in the gut microbiome, induce oxidative stress, and impair organ function [2][5]. The risk becomes more significant when these plastics accumulate in edible tissues, as demonstrated in several studies of fish and shellfish consumed by humans [21][27].

These results reinforce the need to include polymer-level data in marine pollution monitoring efforts. Many studies still report only total microplastic abundance or morphology without specifying the polymers involved. This review highlights the importance of identifying polymer types for understanding ecological impacts, tracking pollution sources, and anticipating potential health risks. A greater emphasis on trophic-level-specific monitoring and standardized reporting would allow for more reliable comparisons and better risk assessment.

4 Conclusions and future perspectives

This systematic literature review synthesizes polymer-specific microplastic contamination across marine trophic levels, based on 16 empirical studies examining ingestion patterns in herbivorous, omnivorous, and carnivorous species. The findings reveal that polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) are the most frequently detected polymers in all trophic groups, reflecting their widespread use in packaging, fishing gear, and textiles, and highlighting their pervasive distribution in marine environments. These polymers consistently appear in species with varied feeding behaviors, indicating their broad ecological penetration and potential for entry into food webs. Moreover, polymer diversity tends to increase with trophic level, with carnivores showing the broadest range of polymer types, including polyvinyl chloride (PVC), polyurethane (PU), polyamide (PA), and polyesters (PEST), likely due to trophic transfer and accumulation through prey consumption. This pattern suggests that higher trophic levels may experience compounded exposure to a wider array of polymer types and associated contaminants. Finally, the toxicological properties of different polymers carry important ecological and human health implications, as materials like PE and PP can adsorb persistent organic pollutants, while PET and PA may retain endocrine-disrupting chemicals or residual industrial additives. These findings affirm the importance of incorporating polymer-level data into marine pollution assessments, both to improve ecological risk evaluations and to better understand potential human exposure through seafood consumption.

Future research on microplastic pollution must prioritize standardized methods for polymer identification, particle quantification, and detection to ensure consistency and comparability across studies. Integrating ecological data with chemical analyses will help clarify how feeding behavior and habitat influence polymer exposure. Greater geographic and taxonomic coverage, especially in regions such as Southeast Asia and among lower trophic-level organisms, is essential for a fuller understanding of contamination pathways. Studies should also examine microplastics in edible tissues to better assess human health risks. Tracing sources through polymer fingerprinting and fostering interdisciplinary collaboration will be key to developing targeted and effective mitigation strategies.

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