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Review article

A comprehensive review on the adverse effect of microplastics in the gastrointestinal system of *Artemia* sp.

Guria Saha, Natarajan Chandrasekaran [*]

Centre for Nanobiotechnology, Vellore Institute of Technology, Vellore, India

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ABSTRACT

Microplastic waste in aquatic environments can lead to the mortality of large marine creatures, as it increases the risk of entanglement, strangulation, and starvation. Even though micro- and nanoplastics pose a hidden threat, researchers still know little about them. The food source is an essential factor in gut microbial diversity. A well-balanced intestinal microbiome impacts animal development and health. According to research, microplastics (MPs) like polyethylene (PE) and polystyrene (PS) affected the gut microbiota of Artemia sp., increasing their genetic diversity. Therefore, the present study examined the negative impacts of MPs within the gastrointestinal tract of *Artemia* sp., the primary protein source of fish. A comprehensive literature review showed that microplastic contamination and its additives impair environmental and aquatic health. The findings of this research show that MPs alter the gut microbiota of Artemia, which in turn affects fish and, ultimately, human health via a cascade of impacts.

1. Introduction

MPs are the byproducts of plastic debris that microbes, waves, ocean currents, and UV light have degraded. These contaminants might get up in water bodies in several ways, including direct routes like rivers and ocean currents and indirect ones like fishing gear and marine debris. Because of their small size and inert nature, MPs can remain in the environment for an extended period and are readily absorbed by the organisms in the surrounding environment [1]. By 2050, the world's plastic production is predicted to surpass 12 billion metric tons per year, up from 4.9 billion metric tons in 2015 [2]. According to the UN Globally Harmonized System (GHS), over half of all plastics include harmful monomers, substances, and synthetic by-products that may affect the ecosystem [3]. MPs come in various forms, including flakes, fragments, fibrils, and foams [4]. Their size and form determine MPs' deterioration and eventual destiny [5]. Solid waste is a significant contributor of MPs to the ecosystem. Landfills are the leading hazardous waste disposal option, and MPs are stored and distributed [6]. Rainfall and wind carry MPs from landfills to ecosystems [7]. Synthetic textile microfibers may pollute wastewater treatment facilities [8]. Additionally, wastewater treatment plant (WWTP) effluents and sewage, including digested sludge or biological solids, can carry MPs from toothpaste, hand cleaners, detergents, and shower gels into the ecosystem [9]. Around 4.8–12.7 tons of PE plastic debris were believed to have entered the seas in 2010 [10]. PS MPs may be found in many forms, such as egg cartons, disposable cups, plates, and bowls [11]. In non-ferrous industries and small workshops, much untreated plastic trash is dumped into the environment [12]. Foods, including fish, honey, vegetables, fruits, beer, and sea salt, might contain MPs due to the widespread use of plastics in food manufacturing and processing. Improper food waste management also releases MPs into the

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[*] Corresponding author.
E-mail address: nchandrasekaran@vit.ac.in (N. Chandrasekaran).

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environment [13,14].

The problem of MP contamination in the world's water supplies is becoming more pressing daily. In recent decades, there has been an increasing concern regarding the potential negative impacts of MPs on aquatic organisms, marine environments, and human well-being [15,16]. One significant issue is the ingestion of high quantities of MPs by aquatic organisms, leading to starvation as they mistake these particles for actual food [17]. These micro and nano plastics have a detrimental effect because of their high surface area-to-volume ratio and capacity to translocate inside an organism [18]. Particles with a diameter of fewer than 5 mm significantly contribute to environmental degradation [19]. There is evidence that these minute pollutants influence a wide range of physiological systems of organisms, including eating behaviour, changes in gene expression, reproductive outputs, tissue inflammation, developmental defects, and the suppression of growth and development (Fig. 1) [20,21]. MPs have recently gained attention as a significant environmental contaminant and stressor [22]. Several studies have shown that aquatic animals are susceptible to stress reactions after ingesting MPs, including changes in behaviour, growth, reproduction, metabolism, and oxidative stress. In addition, other animals in the food chain are put at risk of developing health problems due to the presence of MPs.

Most MP studies have examined submicron-to-micrometre MP ingestion and its consequences. Zooplankton ingested particles in this size range because they resembled their diet [23,24]. Previous research examined four distinct MP pollutants obtained from two face cleansers, a plastic bag, and a PE textile fleece, all ecologically significant [25]. Plastic particles were discovered within the digestive systems of both *D. magna* and *A. franciscana* in all MP exposures (Fig. 2) [25]. MP polymers have varying levels of toxicity when broken down into their constituent monomers. Additionally, the toxicity of MPs is affected by the distribution of MP particle sizes. Using the given criteria, a semi-quantitative risk assessment methodology has been created to prioritise MP polymers that may pose health risks when exposed to marine environments. The screening technique ranked the polymers of concern in decreasing order, with PUR, PVC, PAN, ABS, PMMA, SAN, TPU, UP, PET, PS, and HDPE being the top-ranking ones. The factors that affected the final risk assessment were found via the sensitivity analysis. These parameters included the risk factor rating calculated using a single molecule categorisation (RF5 coefficient + 0.60), the variation in the particle size of MPs (RF4 + 0.54), yearly world waste production (RF1 + 0.52), the state of deterioration in the marine ecosystem (RF3 + 0.32), and average density of polymer compounds (RF2 + 0.16) [26].

Marine creatures absorb MPs [27], which affects their diet (Wegner et al., 2012), energy, and reproduction. MPs also induce cytotoxicity [27,28], neurological impairment, acute inflammation, DNA damage, and histopathological abnormalities (von Moos et al., 2012) in aquatic species [29,30]. Most MP impact studies include the common cockle, *Mytilus edulis* [31]; however, bivalves with different feeding habits are rarely studied. MP consumption is a growing concern; hence, studies on species with varying feeding methods are crucial [32]. Weathering-induced plastic product fracture and surface degradation on beaches significantly contribute to MPs [33]. MPs are unevenly distributed throughout the world's oceans [34]. Aquaculture organisms constitute a significant source of high-quality protein. MPs pollution in fish via Artemia may pose various hazards to human health, making aquatic products unsafe for human well-being.

The brine shrimp significantly facilitates energy transfer across various trophic levels within diverse marine ecosystems [1]. Artemia is a group of aquatic crustaceans often referred to as brine shrimp. The group consists of seven to nine species that most likely originated from a common ancestor inhabiting the Mediterranean region around 5.5 million years ago during the Messinian salt crisis [35]. Using Artemia as a live feed represents a highly advantageous means of providing fish with a substantial protein source. While it contains the necessary proteins, it is suitable for development and general well-being [36]. Research shows that Artemia has excellent digestion rates when given to carp and rainbow trout and reasonable values for protein efficiency ratio and net protein consumption [37]. Furthermore, it has a high concentration of omega-3 fatty acids, associated with enhanced immunity and decreased inflammation in fish. The *Artemia salina* species is the most commonly utilised commercially [38]. Today, hatcheries depend on three categories of live feed: different kinds of microscopic algae, rotifer *Brachionus*, and the *Anostraca* brine shrimp Artemia [39]. Artemia, due to its convenient hatching process from readily available dried cysts, is widely favoured as a live meal for fish and crustacean larviculture.

MP uptake has been observed in various aquatic creatures within the ecosystem. These organisms include fish [40–42], bivalves [43], invertebrates [44,45], and zooplankton [46–48]. These organisms can consume MPs as sources of food. This can occur accidently

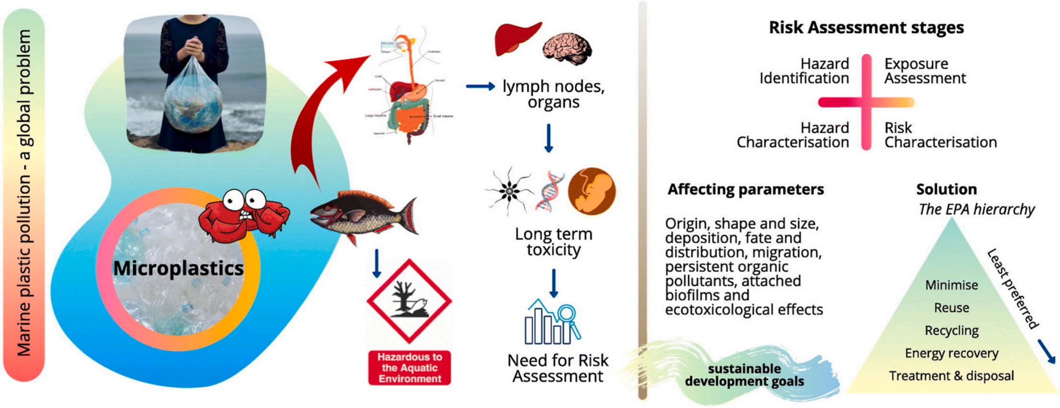

Fig. 1. Effects of microplastics in marine ecosystem. This image is obtained from Yuan, Nag [21].

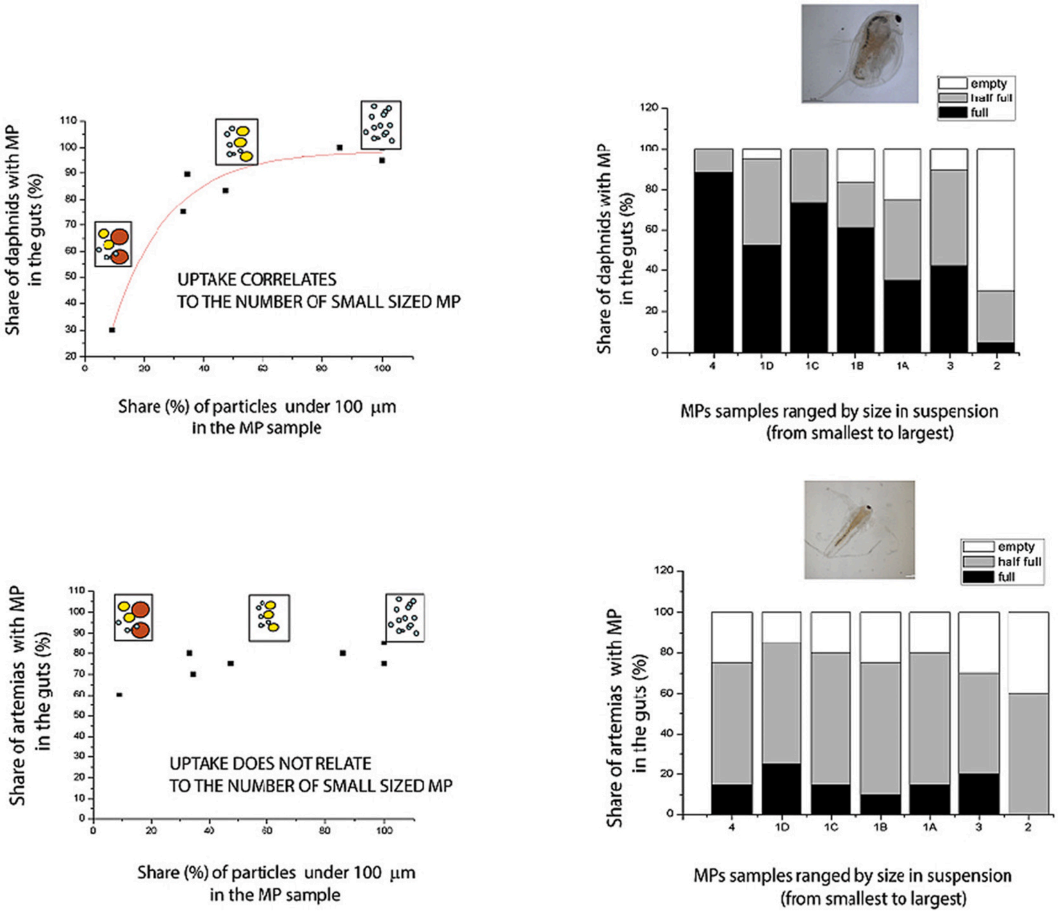

Fig. 2. Uptake and effects on Daphnia magna and *Artemia franciscana* [25].

when they capture MPs while filter-feeding or deposit-feeding. They may also mistake MPs for prey while seeking food. Additionally, they can consume MPs indirectly by ingesting organisms from lower trophic levels that contain these fragments [49]. According to various studies, it has been found that microbial metabolisms such as phosphorous acquisition, genome-wide transcriptional alterations, nitrogen fixation rates, protein production, and photosynthesis have all been shown to be negatively affected by plastic pollution [50,51]. A study reported that exposure to specific plastic leachates had detrimental effects on the development, genome-wide transcription, and photosynthesis of *Prochlorococcus*, a prevalent marine cyanobacterium [52]. As a crucial intermediate step between primary producers and secondary consumers, zooplankton is pivotal in the food chain. Prior experimental findings have indicated that the consumption of MPs by Artemia can induce changes in the composition of the intestinal microbiota, resulting in a reduced growth rate. MPs are predominantly located within the intestinal tract, and their presence has been observed to have discernible impacts on the gut microbiota [53].

MPs have emerged as a prominent subject of scientific research in recent years. They find their way into the ocean from many different places. Because of their small size and pervasiveness, MPs threaten marine species, particularly filter feeders, due to their harmful impacts and the fact that they can be consumed. Artemia as a species has been studied extensively to learn how MPs affect living organisms [50]. Future studies should build on the findings of this critical assessment of ecotoxicological research on plastic particles and the digestive tract of Artemia, which has been presented in this review. This paper examined the link between MPs and aquatic life to encourage sustainable plastic use in aquaculture.

2. Methodology

A comprehensive literature search was conducted in Scopus, a scientific database. Additionally, Google Scholar was implemented to locate the papers absent from the initial 15 pages. A language filter was implemented to identify publications that contained abstracts in English. To retrieve the associated articles that fall under the category of article title, abstract, and keywords published between 2018 and 2024, the search list contained the following keywords:

“Artemia sp.” OR “Artemia” OR “gut” OR “microplastics” OR “nanoplastics” OR “MPs” OR “NPs”

AND

“ecotoxicity” OR “toxic effects” OR “ecotoxicological effects” OR “cytotoxicity” OR “aquatic organism” OR “crustaceans” OR “brine shrimp” OR “internalisation”

Among the publications obtained, the search yielded more than 300 articles. The ENDNOTE program was then used to input all of the articles, and any duplicate entries were removed from the resultant library. Consequently, we conducted a comprehensive and unbiased evaluation of the publications to eliminate any studies that needed to be more pertinent. Subsequently, the abstracts of the remaining publications were meticulously reviewed and evaluated to determine the most relevant research. The complete manuscripts were meticulously reviewed to ensure they satisfied the specific inclusion criteria and resolved any ambiguity in the articles. Ultimately, 26 collected articles were evaluated to extricate the requisite information, ensuring they satisfied the inclusion criteria and were pertinent to the research objectives. All the collected articles are represented in Table 1.

3. Toxic effects of microplastics on Artemia sp.

Invertebrates have been the target of many investigations into the toxicological implications of MPs in the past few decades. These studies have consistently reported various adverse effects, including minimized feeding and energy reserves, nutritional starvation, incorporation of MPs into body tissues, and severe harm to the gastrointestinal tract [16,54,55]. It has been observed that contact with PS MPs in brine shrimp resulted in elevated levels of Crammer protein and pyrimidodiazepine synthase [56]. This upregulation

Table 1
Previous literature (2018–2024) showcasing the effects of microplastics on *Artemia* sp.

Srl No.	Title of paper	Publishing year	Reference
1.	Microplastic size matters for absorption and excretion by *Artemia salina* and *Acipenser ruthenus* larvae in models of water pollution and food chain transfer	2024	[66]
2.	Naturally weathered polypropylene microplastic from environment and its toxic behaviour in *Artemia salina*	2024	[85]
3.	Effects of salinity on naphthalene adsorption and toxicity of polyethylene microparticles on *Artemia salina*	2024	[86]
4.	A combined toxicological impact on *Artemia salina* caused by the presence of dust particles, microplastics from cosmetics, and paracetamol	2024	[87]
5.	Investigating on the toxicity and bio-magnification potential of synthetic glitters on *Artemia salina*	2023	[79]
6.	The genus Artemia, the nanoplastics, the microplastics, and their toxic effects: a review	2023	[83]
7.	Toxicity assessment of bioplastics on brine shrimp (*Artemia franciscana*) and cell lines	2023	[68]
8.	Long-Term Toxicity of 50-nm and 1-μm Surface-Charged Polystyrene Microbeads in the Brine Shrimp *Artemia parthenogenetica* and Role of Food Availability	2023	[88]
9.	Comparative toxicity of polystyrene, polypropylene, and polyethylene nanoplastics on *Artemia franciscana* nauplii: a multidimensional assessment	2023	[62]
10.	Isolation and characterization of microplastics from skin care products; interactions with albumin proteins and in-vivo toxicity studies on *Artemia salina*	2023	[53]
11.	Toxicity evaluation of polypropylene microplastic on marine microcrustacean *Artemia salina*: An analysis of implications and vulnerability	2022	[82]
12.	Effect of short-term exposure to fluorescent red polymer microspheres on *Artemia franciscana* nauplii and juveniles	2022	[89]
13.	Sub-acute exposure to nanoplastics via two-chain trophic transfer: From brine shrimp *Artemia franciscana* to small yellow croaker Larimichthys polyactis	2022	[90]
14.	Effect of polystyrene microplastics and temperature on growth, intestinal histology and immune responses of brine shrimp *Artemia franciscana*	2021	[61]
15.	The Influence of Polystyrene Microspheres Abundance on Development and Feeding Behavior of *Artemia salina* (Linnaeus, 1758)	2021	[78]
16.	Influence of Microplastics on the Growth and the Intestinal Microbiota Composition of Brine Shrimp	2021	[1]
17.	Synthetic and natural microfibers induce gut damage in the brine shrimp *Artemia franciscana*	2021	[67]
18.	Single and combined toxicity of amino-functionalized polystyrene nanoparticles with potassium dichromate and copper sulfate on brine shrimp *Artemia franciscana* larvae	2021	[91]
19.	Pharmaceutical Products and Pesticides Toxicity Associated with Microplastics (Polyvinyl Chloride) in *Artemia salina*	2021	[92]
20.	Acute and chronic effects of polystyrene microplastics on brine shrimp: First evidence highlighting the molecular mechanism through transcriptome analysis	2020	[56]
21.	Microplastics and sorbed contaminants – Trophic exposure in fish sensitive early life stages	2020	[93]
22.	Polystyrene microplastics induce mortality through acute cell stress and inhibition of cholinergic activity in a brine shrimp	2020	[94]
23.	Time-dependent effects of polystyrene nanoparticles in brine shrimp *Artemia franciscana* at physiological, biochemical and molecular levels	2019	[95]
24.	Uptake and effects of different concentrations of spherical polymer microparticles on *Artemia franciscana*	2019	[65]
25.	The uptake and elimination of polystyrene microplastics by the brine shrimp, *Artemia parthenogenetica*, and its impact on its feeding behavior and intestinal histology	2019	[70]
26.	Effects of ingested polystyrene microplastics on brine shrimp, *Artemia parthenogenetica*	2018	[69]

suggests increased reactive oxygen species (ROS) generation and accelerated apoptosis following exposure to PS MPs. While several studies have indicated the biotoxicity of MPs on brine shrimp, it is worth noting that most of these studies have focused on exposing the organisms to high concentrations of MPs over a relatively short duration [1,56]. These researches showed that alterations in the microbiota of the gastrointestinal tract triggered by MPs will influence the development and growth of fish and other aquatic animals [57]. However, new experiments and research are needed to observe the effects of MPs on Artemia for long periods. Additionally, the exact mechanism for toxicity also needs to be followed.

Exposure to MP may occur in freshwater and saltwater zooplankton species due to their direct interaction with suspended MP in the top water layers [24]. PS concentrations in near-surface waters were measured at 228 ± 350 particles/m^3 and 148 ± 424 μg/m^3 [58]. The detrimental effects of MPs on crustaceans that are part of the zooplankton community have been previously noted. According to a study, PS particles measuring 50 nm in diameter at concentrations exceeding 50 mg/L were found to impact the motility and moulting process of *Artemia franciscana* larvae after a 48-h exposure period [59]. It was demonstrated that brine shrimp can consume carboxylated PS particles measuring 40 nm and PE particles ranging from 10 to 20 μm in size [60]. Though this is an old study on the effects of nanoplastics, the impacts of microplastics need to be conducted. Investigation revealed that Artemia had a lower concentration of MP particles in their digestive system than daphnids. This disparity may be attributed to their distinct preferences for meal size. *Daphnia magna* did not show any immediate impacts; however, the development of *Artemia franciscana* was adversely impacted. *A. salina* exposed to 2.5 mg/mL of these MPs from facial scrubs and cleansers delayed hatching and development. Additionally, these MPs were shown to be absorbed in the gut after 144 h of exposure [53]. From the studies mentioned above, we can conclude that NPs cause more toxic effects than MPs. This was mainly because of the small size of the NPs, which are easily internalized into the organism.

4. Effects of microplastics on the growth of Artemia sp.

The existence of marine species and their varieties has been threatened by pollution from MPs and rising ocean temperatures. Previous studies found that temperature significantly affected Artemia growth and that temperature and light intensity interacted substantially [61]. They also showed that, when exposed to high temperatures and concentrations of PS MPs, the results have detrimental effects on Artemia. Based on the findings of a study, it has been demonstrated that the introduction of MPs has significantly decreased the growth rate of brine shrimp. An investigation was conducted to examine the impact of PS and PE MPs on the growth of brine shrimp (*Artemia parthenogenetica*) and the subsequent alterations in gut microbiota [1]. Throughout the development period, both PE and PS MPs exhibited a significant decrease in the growth rate of Artemia and the standard body length of adult brine shrimp. They observed that the size of Artemia was reduced by 17.92 % and 14.95 % from their original length upon exposure to PE and PS, respectively. The study's findings indicate a substantial proportion of MPs accumulated in the intestinal tract. This accumulation can potentially cause intestinal blockages, decreasing the feeding rate of brine shrimp. Ultimately, this can lead to a reduced growth rate in brine shrimp.

A study by Sultan, Wei [62] observed impaired growth and high mortality rates when Artemia franciscana was exposed to PS, PP, and PE of varied concentrations (0.05, 0.5, 5, and 50 mg/L) for 48 h. They also observed histopathological damage in the digestive tract of the nauplii. However, they did not observe the long-term effects of these MPs on the organism. Additionally, MPs that have not been eliminated from the gastrointestinal tract have the potential to cause harm to the epithelial cells lining the digestive system. PE MPs significantly inhibited brine shrimp's development rate more than PS MPs. Upon reaching the stable growth stage, it has been found that the average rate of development of Artemia in the PE group was comparatively lower than that of brine shrimps in the PS group. This observation indicates that PE and PS have varying toxicity levels towards brine shrimp. Hence, it is plausible that MPs' varying physiological, chemical, and surroundings (MPs) contribute to the divergent toxic effects observed in aquatic organisms. The consumption of MPs can adversely affect brine shrimps, including physical obstruction and biochemical process toxicity. This has the potential to harm the cells lining the brine shrimp's intestines, which may lead to inflammation and a disturbance in the metabolism of materials and energy. Consequently, the growth of brine shrimps may be inhibited [1].

5. Microplastic uptake by Artemia sp.

Recent environmental studies have mainly concentrated on MP's possible negative impacts on multiple organisms [63,64]. Planktonic species like Artemia sp. might be adversely affected by the widespread presence of MPs in aquatic ecosystems. Artemia may risk human well-being if fed to fish in their live form because pollutants may be passed up the food chain and into the fish's edible flesh [65]. A study of the effect of ingesting MPs on certain marine organisms has been conducted. However, more research is needed on consumption, removal, and histopathological responses to MPs. Recent scientific research has indicated that Artemia sp. can ingest MPs via consuming mechanisms and trophic interactions [1,59,61,65–70]. These activities have been found to cause physical damage to the gastrointestinal tract, leading to decreased food intake and disturbances in the reproduction process, among other consequences [14,71–74]. Zooplankton serve crucial functions in the marine food web, including the transmission of energy and the movement of contaminants [75]. After ingesting MPs, some zooplankton are shown to have changes in their ingesting, development, and reproductive success. Animals ingest MPs and pass them on via their food chains. Recent research has revealed that *Artemia parthenogenetica* larvae can eat and ingest 10 μm PS microspheres, influencing their overall well-being. The findings suggest that the ability of *A. parthenogenetica* larvae to consume 10 μm PS microspheres is controlled by the concentration and duration of exposure to MPs and available food resources [55,60].

6. Impact of microplastics on the gut of Artemia sp.

Plastics have a range of adverse effects on the species that consume them, including mechanical, chemical, and biological impacts. The consumption of plastics, whether through direct ingestion or trophic-level transfer, has several direct consequences. It can decrease appetite, affect feeding behaviour, and reduce body weight, fitness, and fecundity [50]. Large plastic masses can be extremely dangerous, sometimes even leading to death in various species, when they block the gastrointestinal tract (Fig. 3b) whereas control studies showed no such accumulation of plastic particles in the gut (Fig. 3a). The body can accumulate smaller plastic fractions, primarily in the gut [76]. However, there have been reports of plastics being transported through the hemolymph and hemocytes of filter feeders, potentially reaching organs like the liver and kidneys. This provides further evidence that microplastics might potentially reach the bloodstream after entering the digestive tract [77]. A recent study by Wang, Zhang [69] observed that despite the lack of significant chronic or acute toxic effects on *A. parthenogenetica* after 24-h- or 14-day exposures, the epithelial cells in the intestine undergo a cascade of responses upon consumption of PS MPs at environmentally relevant concentrations. Another study found that *A. franciscana* was very susceptible to the toxicity of PE terephthalate microfibers, but the lyocell had the most negligible adverse effects. A group of researchers observed dye leakage in the gastrointestinal layer, and they determined that A. franciscana, exposed to synthetic or natural microfibers, suffered gut injury [67]. Since most MPs end up in the intestines, it stands to reason that exposure changes the microbiota there. When it comes to marine ecosystems, one of the most significant issues is nano-sized PS polymers. These polymers may spread throughout the water system, harming planktonic organisms and causing energy flow disruptions. The research found that *Artemia franciscana* accumulated PS nanoparticles in their digestive systems after 48 h of exposure. This suggests that nano-sized PS are continuously bioavailable to planktonic species and may even be transferred down the food chain. Hence, due to the crucial function of zooplankton in aquatic food chains, nano-sized PS may be able to hinder the eating, behaviour, and metabolism of brine shrimp larvae, which might have effects on the ecosystem [9].

There have been reports of intestinal injury even when there are very few levels of plastic fragments in the intestines or when particles are eliminated [70]. A recent study by Han, Zheng [61] observed a reduced survival rate of *Artemia franciscana* when exposed to 0, 0.2, and 2.0 mg/L of MPs. Furthermore, they also found the cause of the reduced survival rate. The findings showed that the three MP doses (0, 0.2, and 2.0 mg/L) were most effective when raised at 30 °C for Artemia in terms of enzymatic activity, immune gene expression and intestinal histology. In addition, they also observed reduced intestinal microvilli and exfoliated epithelial cells in *A franciscana*, which in turn significantly increased the acid phosphatase (ACP) activity, and immune-related gene ADRA1B and CREB3 expression. Accordingly, they suggested that Artemia at 30 °C might experience oxidative and immunological stress due to elevated MP concentrations. The only drawback of their study was that they did not observe the long-term effects of the MPs of the same concentration. Similarly, Albano, Panarello [78] observed PS microspheres accumulate in the gut of Artemia salina, which affects the organism's development. However, Frank, Interesova [66] observed an opposite trend, where PS MPs did not accumulate in the gut of *A. salina*. They concluded that this might be because of the size variation of the PS MPs. On the other hand, changes in the inner gut wall of *Artemia salina* were observed when exposed to plastic-made synthetic glitters, as reported by Pramanik, Lei [79]. Substantial damage to the basal lamina was seen, which may have resulted from an invasion of secretory cells. These tall columnar cells dwell in secretory granules, which consist of lysosomes and acid, within their cytoplasm. This combination has the ability to degrade basal and epithelial lamina layers and reduce lipid droplets. These changes could have a detrimental impact on the metabolic functions of *A salina*. A different set of laboratory experiments by Charoeythornkhajhornchai, Kunjiek [68] showed that *Artemia franciscana* (Fig. 4a) digested PE, PLA, and PBS microplastics (Fig. 4b and c) accumulated in the gut. These internalized microplastics cause damage to the underlying epithelial cells and distorted gut microvilli (Fig. 4e and f). However, they did not observe any damage to the macrostructure of Artemia (Fig. 4d). In addition, recent studies have shown that plastics can negatively affect organisms, including oxidative stress, genomic instability, transgenerational toxicity, immunological responses, neurotoxicity, embryotoxicity, disruption of the endocrine system, and reproductive abnormalities. These effects have been observed in Artemia, leading to an increased mortality rate. The

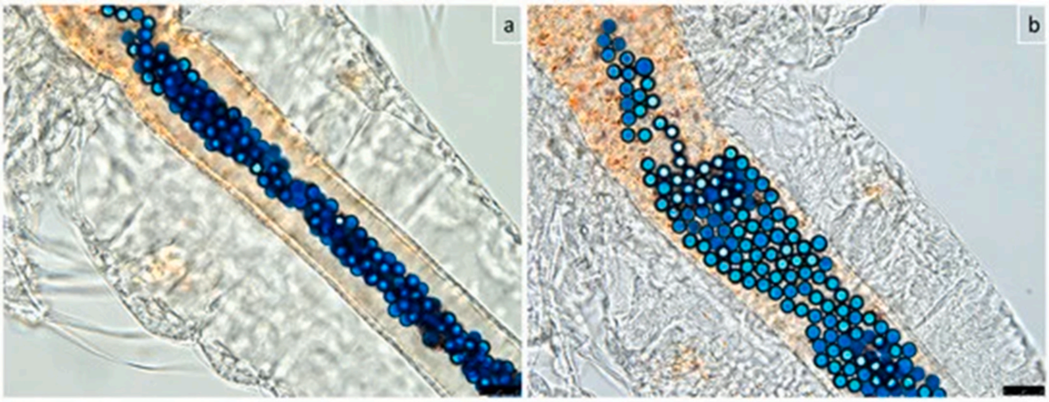

Fig. 3. Uptake and accumulation of microplastics in the gut of *Artemia salina*. The image is obtained from Albano, Panarello [78]. **(a)** Standard view; **(b)** view of the same specimen gently crushed with the cover slide.

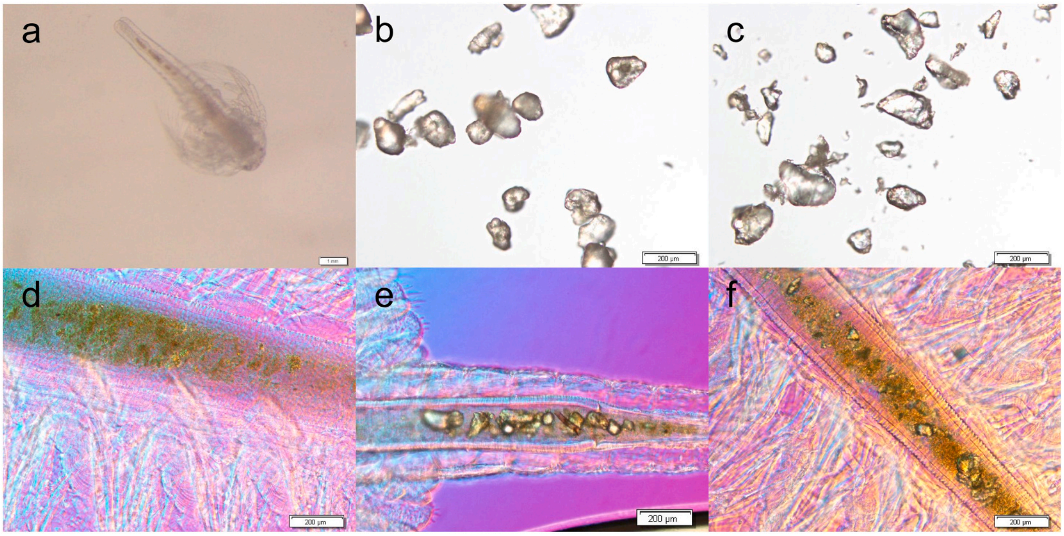

Fig. 4. Microscopic photos of brine shrimp **(a)**, PE MPs **(b)**, and PS MPs **(c)**, and brine shrimp intestines (untreated) **(d)**, treated with PE **(e)** and treated with PS **(f)** [1].

effects of MPs on the gut of Artemia sp. has been graphically represented in Fig. 5.

7. Impact of microplastics on the gut microbiome of Artemia sp.

Ingesting MPs may alter the gut microbiota makeup and cause brine shrimp to develop more slowly, according to the findings of one of the research experiments [1]. While some studies have shown that MPs may be harmful to brine shrimp, these studies often include very high concentrations of MPs exposed for very short periods, and little is known about how the gut microbiota changes following prolonged exposure to MPs. Hence, the objective of this article is to investigate how brine shrimp's gut microbiota reacts to exposure to MP.

Additionally, studies have identified detrimental effects on the gastrointestinal tract in acute exposure tests, even when larval inactivity was not noted [56,69]. Increased variety and abundance of gut microbiota was another effect of ingesting PS and PE MPs [80]. The potential risk of plastic contamination in brine shrimp must be assessed by studying their morphological and physiological gut integrity, as most investigations have shown plastic particles accumulating in their intestines. Since research on gastrointestinal damage is currently limited to MPs, this is particularly pertinent to long-exposure testing with NPs. Evidence has shown that consuming MPs from brine shrimp might modify the makeup of their gut microbiota and result in a reduced growth rate. In the PE group, the standard body width of brine shrimps decreased by 17.92 %. In the PS group, the average body size of brine shrimps decreased by 14.95 %. MPs are primarily located in the intestine, which impacts gut flora. The exposure of MPs substantially enhanced the gut variety of microbes. The PE group had a 45.26 % rise in Actinobacteria and a 2.73 % increase in Bacteroidetes. The PS group had a value of 54.95 and a percentage of 1.27 %. The experimental findings indicate that the consumption of MPs by brine shrimp may

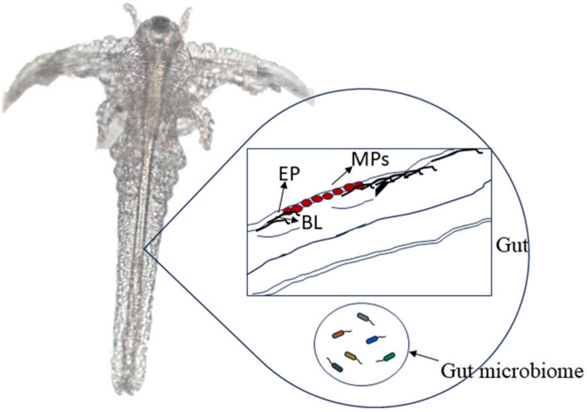

Fig. 5. Epithelial layer (EP), Basal layer (BL) hampered due to internalization of microplastics (MPs) into Artemia gut, along with gut microbiome also affected.

modify the makeup of the intestinal bacteria and result in a reduced rate of development [1]. While lyocell had the least detrimental effect, prior studies showed that PE terephthalate microfibers greatly enhanced mortality in *A. franciscana* [67]. The study examined the gut damage in *A. franciscana* exposed to microfibers by observing dye leakage through the gut layer. The findings indicate that gut injury was seen in all groups subjected to synthetic and organic microfibers. Other research groups also observed similar findings [67,69,70,81,82].

8. Conclusion and future recommendations

Pollution from MPs is a substantial environmental problem threatening marine life and biodiversity. The findings' significance is their ability to enhance the understanding of possible ecological hazards associated with MPs on aquatic organisms [83]. Plastic particles are now thought to be significant contributors to stress for zooplankton. Therefore, ecosystems are at risk as a result of plastic pollution. Ecotoxicological study on the impacts of plastic fragments on biodiversity might benefit significantly from brine shrimp because of their biological position at the base of the food web, their simplicity of use in labs, the rich understanding of their physiology, and their ubiquitous usage in toxicological research [83]. Under the influence of MP, the percentage of Proteobacteria found in the gut of brine shrimp decreased, but the rates of Bacteroides and Actinomycetes showed a considerable rise [1]. The sudden surge in Bacteroides resulted in an imbalance among the populations of microorganisms, which may have influenced the substance metabolic process of brine shrimp, leading to their delayed development. The results of this study show that MPs change the microbes in the gut of Artemia, which in turn impacts aquatic creatures like fishes [84], resulting in ramifications for the health of human beings.

The unravelling of ecological consequences may require methods for combination toxicity, which may be advantageous for studying mixed plastic-chemical effects. This is because MPs may serve as both a direct and an indirect hazard. Due to the many ecological and taxonomic similarities across resident species, many environmental concerns of MPs established in aquatic species will also apply to terrestrial ecosystems. This is the case even though land is the environmental compartment that has received the slightest research. To get a better understanding of how organic chemical partition coefficients to plastics are affected by the presence of silt and soil, it is necessary to conduct experiments on the dynamic interactions between plastic particles, plasticiser additives, and environmental contaminants. It is also necessary to research the chemical dynamics that occur inside the digestive tracts of organisms to get a deeper comprehension of the mechanisms that regulate the bioaccumulation of plasticizing agents and co-transported hazardous substances. Ultimately, it is necessary to research and establish a connection between the findings obtained from the field studies and the laboratory findings. This will allow for better understanding of the implications of MPs in the real world and the processes responsible for them.

This review emphasises the significant gaps in our knowledge of microplastic contamination in aquatic environment, particularly sources, environmental concentrations, and ecological impacts. There has been a substantial increase in our understanding of microplastic concentrations in freshwater systems. However, the connection between this knowledge and its environmental effects has yet to be explored in most cases. It is challenging to evaluate the precise toxicity of microplastics in these systems and to predict the consequences of microplastic presence due to the lack of quantitative data. In contrast to chemical contaminants that have been the subject of substantial study, microplastics clearly still need more clarification from the scientific community about their long-term consequences. We don't know nearly enough about the amount, make-up, and variety of microplastic that make it into the environment. There is a wealth of data accessible, including manufacturing scale and plastic input into main waste management systems. The exact rates of 763 discharges from these streams, caused by either intentional or unintentional waste release or weather action, have not been determined yet. This unintentional release and trashing pathway is a significant source of uncertainty when predicting emissions. This review emphasises the intricate task of comprehending the intricacies and consequences of microplastics as a pollutant in the environment, particularly in terrestrial and freshwater settings. Furthermore, it demonstrates how hypotheses or predictions about these understudied systems may be derived from oceanic research. Studies of nanomaterials may also provide light on particle behavior and fate. Though it would be great if we could reduce the quantity of trash that ends up in the ocean, it is essential to acknowledge the challenges associated with changing manufacturers and consumer behaviour. As a result, plastic releases will likely continue for the foreseeable future. Considering the significant amount of plastic in the environment and the expected rise in microplastics caused by their breakdown, it is crucial to comprehend the possible consequences of this continuously growing pollution.

Data and code availability

Data will be made available on request.

CRediT authorship contribution statement

Guria Saha: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Natarajan Chandrasekaran:** Visualization, Validation, Supervision, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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