water

MDPI

Review

Microplastics as Emerging Contaminants: Challenges in Inland Aquatic Food Web

Prajna Ritambhara Swain [1,2,†], Pranaya Kumar Parida [1,3,*,†], Priti Jyoti Majhi [1], Bijay Kumar Behera [1,4] and Basanta Kumar Das [1]

1 ICAR-Central Inland Fisheries Research Institute, Barrackpore, Kolkata 700120, India; prajna.rit@gmail.com (P.R.S.); meet2pritijyoti@gmail.com (P.J.M.); beherabk18@yahoo.co.in (B.K.B.); basantakumard@gmail.com (B.K.D.)
2 National Fisheries Development Board (NFDB), Eastern Regional Centre, Bhubaneswar 751002, India
3 Caribbean Regional Fisheries Mechanism (CRFM), Kingstown P.O. Box 2427, Saint Vincent and the Grenadines
4 National Fisheries Development Board (NFDB), Hyderabad 50052, India
* Correspondence: pranayaparida@gmail.com
† These authors contributed equally to this work.

Abstract: Microplastic (MP) pollution in inland water bodies, such as rivers, lakes, and reservoirs, is a growing environmental concern, yet research on its ecological impacts in freshwater ecosystems remains limited compared to marine environments. Microplastics, defined as particles smaller than 5 mm, have been detected in freshwater systems globally, and their presence is widespread across diverse aquatic habitats. This review examines the sources, distribution, persistence, and ecological consequences of microplastics in freshwater ecosystems, emphasizing their bioaccumulation in *organisms* from plankton to fish, and the potential risks to human health through microplastic-contaminated fish consumption. Ingestion of microplastics by aquatic organisms can cause physical harm, such as entanglement, and chemical toxicity, including oxidative stress and the accumulation of harmful substances. The trophic transfer of microplastics through the food web raises concerns about higher-level organisms, including humans. Despite these risks, significant knowledge gaps exist regarding the long-term effects of microplastics on freshwater ecosystems. The review calls for improved monitoring, mitigation strategies, and regulatory frameworks to address this issue. Further research is needed to understand the full extent of microplastic pollution in freshwater environments and its impacts on both biodiversity and human health.

Keywords: microplastic impact; aquatic food chain; trophic transfer; bioaccumulation

check for updates

Academic Editors: Jian Liu and Changchao Li

Received: 17 November 2024
Revised: 8 January 2025
Accepted: 10 January 2025
Published: 13 January 2025

Citation: Swain, P.R.; Parida, P.K.; Majhi, P.J.; Behera, B.K.; Das, B.K. Microplastics as Emerging Contaminants: Challenges in Inland Aquatic Food Web. *Water* **2025**, *17*, 201. https://doi.org/10.3390/w17020201

1. Introduction

Plastics are among the most versatile and widely used materials globally [1]. Invented in the early 19th century, this synthetic polymer is durable, inexpensive, and easily molded to meet various needs. However, the extensive use of single-use plastics generates significant waste, leading to persistent environmental pollution. Plastic debris diminishes the esthetic and recreational value of ecosystems and poses long-term risks due to its low recovery rate and poor biodegradability, resulting in bioaccumulation in organisms and the environment [2–5]. Plastic debris in the marine environment was first reported in the 1970s [6] and has since spread rapidly due to increasing global production. Over just a few decades, plastic waste has infiltrated terrestrial ecosystems, inland waters, oceans, remote islands, and even deep-sea regions. This growing crisis threatens marine and aquatic life and endangers terrestrial animals, some of which mistakenly ingest plastics, such as polythene, confusing them for food. The global escalation of plastic pollution underscores the urgent need for effective solutions.

Water covers 71% of Earth's surface, with 97% being saline and only 3% freshwater. Of the freshwater, 1% exists in inland waters, while 2% is stored in ice and glaciers. Human activities on the 29% of land surface are the primary source of plastic debris, with freshwater systems serving as key pathways for transporting plastic waste to the oceans [7]. According to Lebreton et al. (2017) [8], 1.15 to 2.41 million tonnes of plastic enter the oceans annually via rivers, with 74% transported between May and October. Asian rivers contribute 67% of this total, led by the Yangtze River, which delivers 0.33 million tonnes annually to the East China Sea, followed by the Ganges River, carrying 0.12 million tonnes to the Bay of Bengal. The United Nations Environment Programme (UNEP) estimates that plastic pollution incurs a financial cost of $13 billion per year [9].

1.1. What Is Microplastic?

Microplastics are tiny plastic particles, typically ranging from a few microns to several millimeters in size, and can appear in shapes from spherical to elongated fibers [10]. Large plastic items in the environment break down into microplastics through various physical, chemical, and biological processes, including exposure to UV light, wave action, ocean currents, and repeated suspension of fragmented materials. Plastic particles smaller than 5 mm are generally defined as "microplastics" [11].

1.2. Source

In marine environments, major contributors include wastewater treatment plants, beach litter, fisheries, shipping, harbors, and industrial plastic production. For inland waters, sources include wastewater plants, industries, tourism, runoff from dumping sites, and sewage and garbage disposal. Sewage sludge, commonly used in landfills and as fertilizer, is a significant source, with runoff from these areas increasing microplastic levels in water bodies [12]. Personal care products and clothing wash are also key contributors to microplastics in wastewater [13,14].

1.3. Different Forms of Plastics

Plastics come in various polymer forms, such as polyethylene, polypropylene, polyvinyl chloride, and polystyrene, with shapes like spheres, fibers, fragments, and films, and sizes ranging from micro to macro. Plastic debris is a mixture of these forms and shapes. This discussion focuses on microplastics and their impacts on inland water bodies and associated organisms. Recently, microplastics have emerged as significant contaminants in aquatic habitats, opening a new dimension in plastic impact studies [15].

1.4. Types of Microplastics

Microplastics are classified into two types based on their origin: primary and secondary. Primary microplastics are directly released into the environment through sewage discharge, runoff, or spills and often appear as fragments, pellets, films, or spheres, commonly linked to the pharmaceutical and cosmetics industries. Fibers and fragments, typically 800–1600 μm in size, are frequently found in aquatic animals [16]. Secondary microplastics result from the degradation and fragmentation of larger plastic debris through processes like photo-oxidation, wave action, and microbial activity. Additionally, a third category, nanoplastics, has been identified. These are ultra-small plastics, measuring 1–100 nanometers, formed through the further breakdown of microplastics [17,18].

2. Microplastic in Inland Waters

Microplastic pollution is widespread in rivers and lakes, which may face greater impacts than marine environments, as rivers are key conduits for plastic debris entering oceans. Land-based plastics are a larger contributor to ocean pollution than marine sources [19], yet inland waters have been less studied. Though research on microplastics (<5 mm) in freshwater environments is limited [12], many reports confirm their presence (Table 1). Factors like size, density, shape, composition, water flow, and hydrodynamics influence microplastic movement, while water chemistry affects their properties and interactions in freshwater ecosystems [7].

Table 1. Occurrences of MPs in different inland water systems.

System	MPs Occurrences	References
Laurentian Lake, USA	43,000 items/km^2 in Surface water	[20]
Lake Huron, Canada	0–34 items/m^2 in shoreline sediments	[21]
Erie and St. Clair lakes, USA	0.2–8 items/m^2 in serdiment	[22]
Sourthern and Northern Shores	100–1100 items/m^2 in sediment	[23]
Los Angeles River	12,000/m^3 in water column	[24]
Danube River, Austria	56–9000 items/m^3 in water column	[25]
St. Lawrence River	152–13,832 items/m^2	[26]
Humber River	5.98–945 g/m^2 in shoreline and bottom sediment	[27]
Yangtze, Jiaojiong, Oujiay, Minjiay Estuaries in China	50–12,000 n/m^3 density of MPs in surface water	[28,29]
Vembanad Lake, India	96–496 items/m^2	[30]
Ganga river, India	1.3–2.42 particles/m^3 Surface water	[31]
	99.27–409.86 items/kg of sediment	[32]

3. Objective of This Study

The primary objective of this review paper on the impact of microplastics in inland water/freshwater environments is to consolidate current knowledge on how microplastics affect the aquatic food web in ecosystems. The goal of this review is to offer an in-depth overview of current research, concentrating on the sources, distribution, and persistence of microplastics in freshwater systems, along with their ecological impacts on organisms across different trophic levels—from tiny plankton and invertebrates to larger aquatic species—while highlighting bioaccumulation and potential human health risks. The review aims to pinpoint essential knowledge gaps and suggest future research.

Ultimately, it will guide researchers, policymakers, and environmental agencies in developing more effective strategies to monitor, mitigate, and regulate microplastic pollution in freshwater environments.

4. Methodology

4.1. Methodology Followed

This review paper involved a structured approach to gathering, analyzing, and synthesizing the existing literature on the impact of microplastics at different trophic levels in the inland aquatic food web. This process began with a comprehensive search of academic databases, such as Google Scholar and Scopus to identify relevant studies on the topic. Specific inclusion and exclusion criteria were established to ensure that only pertinent studies were selected focusing on publication date and fresh water environment/inland waters in particular. The majority of the included studies were published during 2012 to 2024. Keywords such as "Impact of microplastic in phytoplankton", "Impact of microplastic in zooplankton", "Microplastics", "inland waters", "Impact of microplastic in freshwater fishes", "Microplastic in inland waters", "Impact of microplastics on benthic invertebrates", "Microplastic impact on human health" were used to refine the results. Following this, data extraction was conducted by summarizing the key findings, methods, and results from each source. The information was categorically organized for a structured discussion. By systematically synthesizing the literature, the review methodology ensures a balanced and comprehensive summary that highlights prevailing conclusions, inconsistencies, and directions for future research. For the analysis of the published literature from Scopus database, the keywords "Microplastics and Freshwater environment" with limitation to the "Environmental science" subject area were used.

4.2. Analysis of the Published Literature

As of 5 November 2024, a total of 172 review papers and 951 research articles on "microplastics" in freshwater ecosystems have been published, according to the Scopus database. Of these, the majority of both the review papers and research articles were published in the last five years, with 816 research articles published during this period (Figure 1). In terms of country contributions to review articles on microplastic, China leads, followed by India and the United States. For research articles, China also holds the top position, followed by the United States and Germany, with the United Kingdom and India ranking fourth and fifth, respectively (Supplementary Table S1). The primary funding for microplastic research has come from China National Natural Science Foundation, followed by the Ministry of Science and Technology of the People, Republic of China and the National Key Research and Development Program of China (Supplementary Table S2).

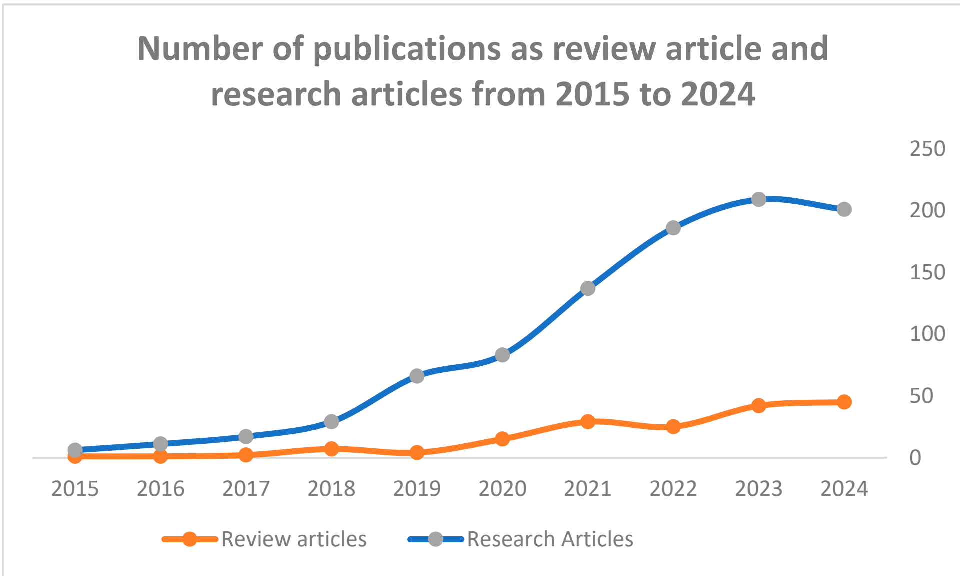

Figure 1. Number of publications as review articles and research articles from 2015 to 2024.

The journal "Science of the Total Environment" has published the highest number of articles, followed by "Environmental Pollution". "Chemosphere" and "Hazardous Materials" contribute nearly the same number of research articles. The other journals ranking in the top 10 for research article publication are listed in Supplementary Table S3. Among the top ten cited research papers, five are published in Elsevier journals, while two are from the American Chemical Society. The most cited paper on microplastics is titled "Emerging Threats and Persistent Conservation Challenges for Freshwater Biodiversity" (Supplementary Table S4).

5. Impact of Microplastic in Inland Aquatic Ecosystem

Although small plastic debris was first identified in the 1970s, the term "microplastics" gained attention in 2004 when R.C. Thompson introduced it in his report "Lost at Sea: Where Is All the Plastic?" [33]. Thompson is often credited as a pioneer in the study of microplastics, a field that continues today. However, research on microplastics in inland freshwater environments has been limited, primarily due to the early focus on marine pollution and the vastness of the oceans, which cover 71% of Earth's surface, while inland waters make up just 1% of the total.

Microplastics are ingested by aquatic organisms as they mimic prey, leading to their accumulation through the trophic chain. Over time, this can pose a potential food hazard for humans [34,35]. Their bioaccumulation potential increases as their size decreases, making microplastics particularly concerning. A variety of organisms, from plankton to fish, birds, and mammals, ingest microplastics directly or indirectly, resulting in bioaccumulation over time [3]. Additionally, the chemicals used in their manufacture [36] and the degradation of microplastics release toxins, which, as they travel, act as vectors for contaminants [37–39]. These toxins significantly affect the growth and survival of aquatic organisms [40].

Microplastics (MPs) severely impact aquatic ecosystems, affecting all levels of the food chain through entanglement, smothering, and ingestion [41,42]. Originating from terrestrial environments, they disrupt the aquatic food chain and ultimately impact human health, creating a cyclical flow with the terrestrial environment as both the starting point and endpoint (Figure 2). The following sections will discuss these effects in detail.

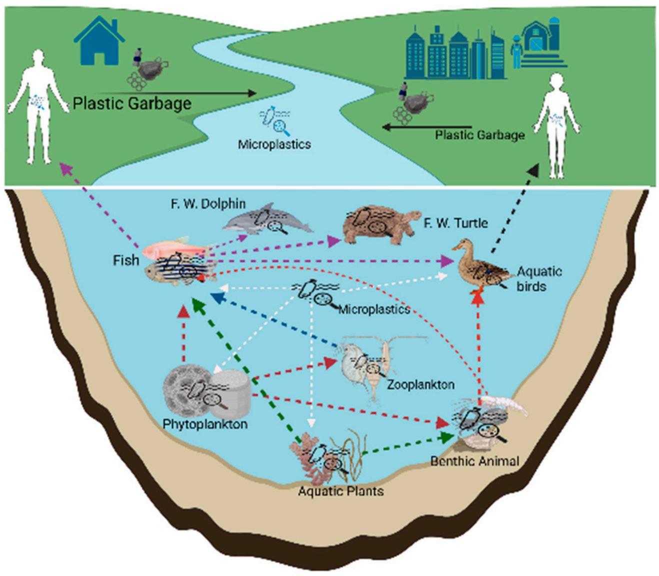

Figure 2. Flow of microplastics in aquatic food chain. The flow of plastic and subsequent microplastics from terrestrial system to aquatic environment and impact on the food chain in aquatic environment and ultimate impact on humans through the food chain. The colour of the dotted arrows in the figure indicates the transfer of microplastic from a particular organism to others within the food web.

5.1. Impacts on Plankton

Plankton form the foundation of aquatic ecosystems and food chains, supporting higher organisms and playing a key role in nutrient cycling. Phytoplankton, as primary producers, are impacted by microplastics (MPs). Studies show that MPs disrupt photosynthesis, alter chlorophyll concentrations [43–45], increase oxidative stress [46], and affect gene expression [47]. MPs also damage algal cells [48] and deplete nutrients [49], while higher concentrations can alter the community structure of algae [50].

Zooplankton, especially copepods and daphnids, ingest MPs directly or through contaminated phytoplankton. Prolonged exposure impacts reproduction, survival, and feeding patterns due to carbon depletion [51]. Copepods and daphnids are more vulnerable to MPs than other groups like mollusks [52]. MPs, combined with toxins like cyanotoxins, further harm rotifers (*Brachionus calyciflorus*), affecting their growth and reproduction [53].

MPs also serve as biofouling agents, altering buoyancy and sinking rates of aquatic organisms [54,55]. While biofouling offers protection from UV rays, it increases plastic consumption by predators [56]. The plastisphere supports a unique community of drug-resistant bacteria, cyanotoxins, and pollutants, potentially impacting plankton diversity and ecosystem dynamics [57].

5.2. Impact on Aquatic Plants

Aquatic plants, like algae, contribute to primary productivity and serve as food for aquatic organisms. Microplastics (MPs) impact these plants similarly by inhibiting root growth, cell viability, and photosynthesis [58]. MPs are absorbed by plant cells, especially on rough surfaces, through electrostatic forces. Plants with periphytic layers retain more MPs due to higher viscosity, while algae generally accumulate more MPs than plants [59].

5.3. Impact on Benthic Invertebrates

In freshwater ecosystems, the benthic community plays a key role in nutrient cycling by breaking down organic compounds for mineralization. However, microplastics (MPs) disrupt this process by affecting benthic flora and reducing food intake [60]. MPs harm both functional and performance traits of benthic organisms, causing short-term toxicity that damages gut epithelium, induces inflammation, and leads to oxidative stress, as well as long-term effects like reduced larval body size and increased emergence time [61,62]. In decapod crustaceans, MPs accumulate in tissues, posing risks to predators [63,64], and cause oxidative stress, immunological disorders, and impaired reproduction and growth [63]. In mollusks, MP accumulation varies based on body size, exposure time, and concentration [65]. Chronic exposure to polypropylene MPs in *Pomacea paludosa* affects redox homeostasis, oxidative stress markers, and the digestive system, causing significant damage to the digestive gland [66]. Additionally, polyethylene MPs reduce the effectiveness of the molluscicide “Niclosamide” in controlling freshwater snails, raising concerns for snail control programs in MP-contaminated environments [67].

5.4. Impact on Fish

Fish, as key predators in aquatic ecosystems, are vital food sources for humans and other higher trophic organisms. Depending on their diet, fish are classified as primary consumers (phytoplankton eaters), secondary consumers (zooplankton eaters), or apex predators. Primary and secondary consumers primarily ingest microplastics (MPs) directly, while apex predators consume them indirectly through prey [68]. Fish microplastic ingestion is more influenced by physiological traits than the environment [69]. Fibers are the most common form of microplastics found in fish, particularly in gut tissues, with juvenile and larval fish also showing microplastic presence [70–72].

Microplastic (MP) uptake in fish is influenced by factors like body size, habitat, feeding behavior, and respiration [73,74]. Fish using visual cues for foraging tend to ingest more MPs than those relying on chemoreception [75,76], while filter feeders may consume MPs through contaminated prey [77]. MPs can also enter fish via drinking and respiration [78,79]. Ismail et al. (2018) [80] found that MP accumulation varied significantly across fish types, with herbivores accumulating more MPs than omnivores and carnivores. In a study conducted in Eleyele Lake, Nigeria, Tilapia (*Oreochromis niloticus*) exhibited the highest prevalence of microplastics (MPs), followed by *Coptodon zillii* and *Sarotherodon melanotheron*, with *Sarotherodon melanotheron* showing the greatest number of plastic particles [81]. Benthopelagic species had higher MP prevalence than demersal species like

Paranchanna obscura and *Chrysicthys nigrodigitatus*, primarily due to differences in feeding behavior and physical structure. Herbivorous fish, with longer intestines, retained more MPs due to prolonged retention times [80]. McNeish et al. (2018) [71] found that zoobenthivorous fish, like *Neogobius melanostomus*, accumulated more MPs than detritivores and omnivores in Lake Michigan, highlighting a positive correlation between trophic levels and MP abundance. Similarly, Wang et al. (2020) [82] reported that omnivorous and filter-feeding fish accumulated more MPs than carnivorous species in the Pearl River and Beijing River deltas. Ferreira et al. (2016) [83] also found that adult *Cynoscion acoupa* in the Goiana Estuary retained more MPs compared to juvenile fish, demonstrating the impact of ontogeny on MP accumulation.

Microplastics (MPs) accumulate in various fish organs through direct ingestion or trophic transfer, disrupting biological functions and hindering growth, which can reduce aquatic system yields [84]. MPs in the gut can irritate the epithelium, causing blockages, inflammation, and digestive issues [71,85]. They can also impair brain function by inhibiting acetylcholinesterase (AChE) activity in Tilapia [86,87]. Lu et al. (2016) [88] found MPs, particularly polystyrene beads, accumulating in tissues like the gills, gut, and liver of zebra fish, leading to inflammation and oxidative stress. Karimi et al. (2016) [89] observed histological damage in African catfish (*Clarias gariepinus*) gills and liver, with changes in blood parameters and external abrasions, particularly at higher concentrations of HDPE fragments (500 µg/ L).

Michailidou et al. (2024) [90] assessed the effects of aged polyethylene (PE) microplastics on the liver and muscle tissues of freshwater fish (*Perca fluviatilis*), finding the liver more affected than muscle tissue. They identified hsp 70, apoptosis, and ubiquitin as the most sensitive biomarkers. The study also revealed that aged PE microplastics impacted antioxidant defense and cellular structure more than virgin plastics. Similarly, exposure to environmentally relevant concentrations (0.1–100 µg/L) of photoaged (UV-radiated) MPs impaired locomotion and caused neurotoxicity in zebra fish larvae [91].

MPs and their additives, like phthalates and bisphenol, act as endocrine disruptors, affecting aquatic organisms' life stages [92–94]. They also disrupt signaling systems, altering predator–prey interactions, population dynamics, and community structures [94–97].

5.5. MPs Impact on Water

In addition to their adverse effects on organisms, microplastics (MPs) also alter the physical properties of water, impacting phenomena such as translucency [98], sedimentation processes [99], and sediment characteristics, including thermal conductivity [100].

5.6. MPs Impact on Aquatic Birds and Other Aquatic Organisms

Birds, as one of the top predators in aquatic ecosystems, are particularly vulnerable to emerging microplastic (MP) pollution. Wang et al. (2021) [101] highlighted the negative effects of MPs on avian growth, reproduction, and other physiological processes. Commonly detected polymers in birds include polyethylene, polyester, and polypropylene [102–104]. Beyond avian species, MPs have also been found in wild populations of aquatic mammals, amphibians, and reptiles [105–108].

5.7. MPs Impact on Human Health

Humans, as apex predators in both terrestrial and aquatic food chains, are significantly exposed to the risks associated with microplastic (MP) pollution. Fish, a critical link between humans and aquatic ecosystems, frequently act as a vector for MP transfer due to their widespread consumption and high nutritional value. Numerous studies have documented the accumulation of MPs in fish tissues, with humans being exposed to MPs through the consumption of whole, canned, or dried fish [84]. In addition to MPs, plastic additives such as phthalates and bisphenols have been shown to disrupt endocrine functions [109,110] and are associated with an increased risk of breast cancer [111,112]. MPs also pose severe health risks, including oxidative stress, genotoxicity, reproductive impairments, and organ inflammation [113]. These effects are particularly concerning for children and infants, who are more susceptible to disruptions in cell proliferation, neurodevelopment, and immune system function [112,114,115].

5.8. Impact as a Whole in the Food Chain

In summary, microplastics influence all components of the aquatic food chain, with subsequent consequences for human health. Their impacts include physical harm, neurotoxicity, cellular damage, immune system disruption, and other adverse effects (Figure 3).

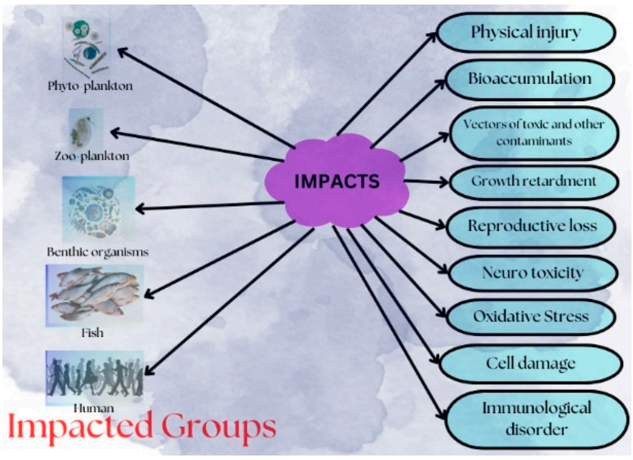

Figure 3. Impact of microplastic. This figure depicts the impacted group in the food chain by microplastic and the impacts by the microplastic to these groups.

6. Recommendations and Policies for Minimizing Microplastic Pollution in Inland Waters

Microplastic (MP) pollution in inland water bodies is a pressing environmental issue that requires immediate attention. The authors have outlined key recommendations and policies aimed at reducing microplastic pollution in these aquatic ecosystems.

- Reduction from source and Plastic Waste Management: Preventing plastics from entering water bodies is vital. Government should enforce bans on single-use plastics (e.g., straws, bags) and promote biodegradable alternatives and plastic-free packaging and usage. Improved waste management systems are essential, particularly in rapidly urbanizing regions. Policies should encourage extended producer responsibility schemes, where manufacturers are responsible for the entire lifecycle of their products [116].
- Improvement of Wastewater Treatment Systems: Wastewater treatment plants should be upgraded to capture microplastics using advanced filtration technologies like membrane bioreactors (MBRs) [117]. Governments should mandate regular monitoring of microplastic levels in wastewater effluents and incentivize innovative technologies, such as bio-filtration or magnetic separation, to remove microplastics at the source [118].
- Monitoring and Research: Investing in research and developing standardized methods to measure microplastics in freshwater systems is essential. Long-term monitoring can help identify pollution hotspots and inform targeted mitigation strategies. Regulatory agencies should require mandatory reporting on microplastic concentrations [119].
- Public Awareness and Education: Public education campaigns on the threats of microplastics and responsible plastic use are required. These programs can focus on

reducing plastic consumption, proper disposal, and responsible usage of plastic like use of personal care products.

- Regulation and Legislation: Governments should establish legal limits for microplastic concentrations in freshwater systems and set guidelines for industries to reduce emissions [120]. Minimization of microplastics in inland waterbodies cannot be achieved by a single country, unless international cooperation is achieved, especially for transboundary rivers, to ensure a global approach to tackling microplastic pollution.
- Incentivizing Innovation in Clean-Up Technologies: Governments should support the development of new technologies for removing microplastics from freshwater systems, such as advanced filtration or autonomous water-cleaning robots [121]. These innovations can help target pollution hotspots and prevent further contamination of larger water bodies.

7. Conclusions

Microplastics, a diverse range of polymers differing in size, shape, and chemical composition, represent a complex environmental stressor with significant, often amplified, impacts. Their widespread presence in freshwater ecosystems poses serious threats to aquatic life, biodiversity, and human health, while compromising water quality. Addressing this issue requires enhanced research to understand microplastic sources, pathways, and effects on aquatic organisms. Effective waste management strategies, including reducing plastic waste and promoting alternatives to single-use plastics, are crucial. Public awareness campaigns can educate communities on sustainable practices. Collaboration among governments, researchers, and local communities is key to developing policies that protect freshwater ecosystems and ensure clean water for future generations.

Supplementary Materials: The supplementary information is pertinent to research papers on microplastics were depicted Supplementary Table S1 (Top 10 countries in publishing review articles and research articles on "Microplastic and "Freshwater" ecosystem), Table S2 (Top 10 funding organization based on the publication on Microplastic and Freshwater ecosystem), Table S3 (Top 10 journals in publishing articles on "Microplastic" and Freshwater ecosystem) and Table S4 (Top 10 Cited papers on microplastic in Freshwater ecosystem). These can be downloaded at: https://www.mdpi.com/article/10.3390/w17020201/s1.

Author Contributions: P.R.S.: Writing the 1st draft. P.K.P.: Writing the 1st draft. P.J.M.: Material collection and review. B.K.B.: Concept and review. B.K.D.: Supervision, review. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by ICAR-CIFRI and NFDB in the preparation of this review.

Data Availability Statement: Secondary data analyzed can be provided on request.

Acknowledgments: The authors gratefully acknowledge the support provided by ICAR-CIFRI and NFDB in the preparation of this review. They also extend their sincere thanks to the researchers whose valuable contributions have advanced our understanding of the impact of microplastics on various components of inland aquatic ecosystems and helped us in writing this review article. We are thankful to the unknown reviewers for the constructive suggestions to improve the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Mira, M.D.R.G.; del Curto, B.; do Nascimento, L.C.P. Product design in plastic materials: The widespread application of plastics in consumer goods and society. In *3rd International Conference on Environmental Design, 3–4 October | Marsala-Sicily*; New Digital Frontiers Srl: Palermo, Italy, 2019; pp. 167–172.
2. Wu, C.; Zhang, K.; Xiong, X. Microplastic Pollution in Inland Waters Focusing on Asia. In *Freshwater Microplastics. The Handbook of Environmental Chemistry*; Wagner, M., Lambert, S., Eds.; Springer: Berlin/Heidelberg, Germany, 2018; Volume 58, pp. 85–99. [CrossRef]
3. Wright, S.L.; Thompson, R.C.; Galloway, T.S. The physical impacts of microplastics on marine organisms: A review. *Environ. Pollut.* **2013**, *178*, 483–492. [CrossRef] [PubMed]
4. Soundararajan, G.; Chidambaranathan, B.; Rajendran, A.K.; Venugopal, D.; Devarajan, Y. Plastic pyrolytic oils as renewable fuel: Improving its physical properties and ignition patterns by waste renewable source—An experimental analysis. *Environ. Sci. Pollut. Res.* **2024**, *31*, 26497–26509. [CrossRef] [PubMed]
5. Yang, C.Z.; Yaniger, S.I.; Jordan, V.C.; Klein, D.J.; Bittner, G.D. Most plastic products release estrogenic chemicals: A potential health problem that can be solved. *Environ. Health Perspect.* **2011**, *119*, 989–996. [CrossRef] [PubMed]
6. Wang, J.; Zhi, T.; Jinping, P.; Qiongxuan, Q.; Meimin, L. The behaviors of microplastics in the marine environment. *Mar. Environ. Res.* **2016**, *113*, 7–17. [CrossRef] [PubMed]
7. Guo, M.; Noori, R.; Abolfathi, S. Microplastics in freshwater systems: Dynamic behaviour and transport processes. *Resour. Conserv. Recycl.* **2024**, *205*, 107578. [CrossRef]
8. Lebreton, L.C.; van der Zwet, J.; Damsteeg, J.W.; Slat, B.; Andrady, A.; Reisser, J. River plastic emissions to the world's oceans. *Nat. Commun.* **2017**, *8*, 15611. [CrossRef] [PubMed]
9. Islam, M.S.; Lee, Z.; Shaleh, A.; Soo, H.S. The United Nations Environment Assembly resolution to end plastic pollution: Challenges to effective policy interventions. *Environ. Dev. Sustain.* **2024**, *26*, 10927–10944. [CrossRef]
10. Thompson, R.C. Microplastics in the Marine Environment: Sources, Consequences and Solutions. In *Marine Anthropogenic Litter*; Bergmann, M., Gutow, L., Klages, M., Eds.; Springer: Cham, Switzerland, 2015.
11. Arthur, C.; Baker, J.E.; Bamford, H.A. NOAA technical memorandum NOS-OR&R-30. In Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris, Tacoma, WA, USA, 9–11 September 2008.
12. Wagner, M.; Scherer, C.; Alvarez-Muñoz, D.; Brennholt, N.; Bourrain, X.; Buchinger, S.; Fries, E.; Grosbois, C.; Klasmeier, J.; Marti, T.; et al. Microplastics in freshwater ecosystems: What we know and what we need to know. *Environ. Sci. Eur.* **2014**, *26*, 12. [CrossRef] [PubMed]
13. Browne, M.A.; Niven, S.J.; Galloway, T.S.; Rowland, S.J.; Thompson, R.C. Microplastic moves pollutants and additives to worms, reducing functions linked to health and biodiversity. *Curr. Biol.* **2013**, *23*, 2388–2392. [CrossRef]
14. Fendall, L.S.; Sewell, M.A. Contributing to marine pollution by washing your face: Microplastics in facial cleansers. *Mar. Pollut. Bull.* **2009**, *58*, 1225–1228. [CrossRef] [PubMed]
15. Rillig, M.C. Microplastic in terrestrial ecosystems and the soil? *Environ. Sci. Technol.* **2012**, *46*, 6453–6454. [CrossRef] [PubMed]
16. de Sá, L.C.; Oliveira, M.; Ribeiro, F.; Rocha, T.L.; Futter, M.N. Studies of the effects of microplastics on aquatic organisms: What do we know and where should we focus our efforts in the future? *Sci. Total Environ.* **2018**, *645*, 1029–1039. [CrossRef] [PubMed]
17. Koelmans, A.A.; Bakir, A.; Burton, G.A.; Janssen, C.R. Microplastic as a vector for chemicals in the aquatic environment: Critical review and model-supported reinterpretation of empirical studies. *Environ. Sci. Technol.* **2016**, *50*, 3315–3326. [CrossRef]
18. da Costa, J.P.; Santos, P.S.; Duarte, A.C.; Rocha-Santos, T. (Nano) plastics in the environment–sources, fates and effects. *Sci. Total Environ.* **2016**, *566–567*, 15–26. [CrossRef] [PubMed]
19. GESAMP. Reports and Studies No. 93. Sources, Fate and Effect of Microplastics in the Marine Environment (Part 2) of Global Assessment. 2016. Available online: http://www.gesamp.org/publications/microplastics-in-the-marine-environment-part-2 (accessed on 11 September 2024).
20. Eriksen, M.; Mason, S.; Wilson, S.; Box, C.; Zellers, A.; Edwards, W.; Farley, H.; Amato, S. Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Mar. Pollut. Bull.* **2013**, *77*, 177–182. [CrossRef] [PubMed]
21. Zbyszewski, M.; Corcoran, P.L. Distribution and degradation of fresh water plastic particles along the beaches of Lake Huron, Canada. *Water Air Soil Pollut.* **2011**, *220*, 365–372. [CrossRef]
22. Zbyszewski, M.; Corcoran, P.L.; Hockin, A. Comparison of the distribution and degradation of plastic debris along shorelines of the Great Lakes, North America. *J. Great Lakes Res.* **2014**, *40*, 288–299. [CrossRef]
23. Imhof, H.K.; Ivleva, N.P.; Schmid, J.; Niessner, R.; Laforsch, C. Contamination of beach sediments of a subalpine lake with microplastic particles. *Curr. Biol.* **2013**, *23*, R867–R868. [CrossRef] [PubMed]
24. Moore, C.J.; Lattin, G.L.; Zellers, A.F. *Working Our Way Upstream: A Snapshot of Land-Based Contributions of Plastic and Other Trash to Coastal Waters and Beaches of Southern California*; Algalita Marine Research Foundation: Long Beach, CA, USA, 2005.

25. Lechner, A.; Keckeis, H.; Lumesberger-Loisl, F.; Zens, B.; Krusch, R.; Tritthart, M.; Glas, M.; Schludermann, E. The Danube so colourful: A potpourri of plastic litter outnumbers fish larvae in Europe's second largest river. *Environ. Pollut.* **2014**, *188*, 177–181. [CrossRef] [PubMed]
26. Castañeda, R.A.; Avlijas, S.; Simard, M.A.; Ricciardi, A. Microplastic pollution in St. Lawrence River Sediments. *Can. J. Fish. Aquat. Sci.* **2014**, *71*, 1767–1771. [CrossRef]
27. Corcoran, P.L.; Norris, T.; Ceccanese, T.; Walzak, M.J.; Helm, P.A.; Marvin, C.H. Hidden plastics of Lake Ontario, Canada and their potential preservation in the sediment record. *Environ. Pollut.* **2015**, *204*, 17–25. [CrossRef] [PubMed]
28. Zhao, S.; Zhu, L.; Wang, T.; Li, D. Suspended microplastics in the surface water of the Yangtze estuary system, China: First observations on occurrence, distribution. *Mar. Pollut. Bull.* **2014**, *86*, 562–568. [CrossRef] [PubMed]
29. Zhao, S.; Zhu, L.; Li, D. Microplastic in three urban estuaries, China. *Environ. Pollut.* **2015**, *206*, 597–604. [CrossRef] [PubMed]
30. Sruthy, S.; Ramasamy, E. Microplastic pollution in Vembanad Lake, Kerala, India: The first report of microplastics in lake and estuarine sediments in India. *Environ. Pollut.* **2017**, *222*, 315–322. [CrossRef] [PubMed]
31. Available online: https://counterviewfiles.wordpress.com/wp-content/uploads/2021/07/quantitative-analysis-of-microplastics-along-river-ganga.pdf (accessed on 13 September 2024).
32. Sarkar, D.J.; Sarkar, S.D.; Das, B.K.; Manna, R.K.; Behera, B.K.; Samanta, S. Spatial distribution of meso and microplastics in the sediments of river Ganga at eastern India. *Sci. Total Environ.* **2019**, *694*, 133712. [CrossRef]
33. Thompson, R.C.; Olsen, Y.; Mitchell, R.P.; Davis, A.; Rowland, S.J.; John, A.W.; McGonigle, D.; Russell, A.E. Lost at sea: Where is all the plastic? *Science* **2004**, *304*, 838. [CrossRef]
34. Seltenrich, N. New link in the food chain? Marine plastic pollution and seafood safety. *Environ. Health Perspect.* **2015**, *123*, A34–A41. [CrossRef] [PubMed]
35. Rochman, C.M.; Hoh, E.; Kurobe, T.; Teh, S.J. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. *Sci. Rep.* **2013**, *3*, 3263. [CrossRef] [PubMed]
36. Dekiff, J.H.; Remy, D.; Klasmeier, J.; Fries, E. Occurrence and spatial distribution of microplastics in sediments from Norderney. *Environ. Pollut.* **2014**, *186*, 248–256. [CrossRef] [PubMed]
37. Bakir, A.; Rowland, S.J.; Thompson, R.C. Enhanced desorption of persistent organic pollutants from microplastics under simulated physiological conditions. *Environ. Pollut.* **2014**, *185*, 16–23. [CrossRef] [PubMed]
38. Zarfl, C.; Matthies, M. Are marine plastic particles transport vectors for organic pollutants to the Arctic? *Mar. Pollut. Bull.* **2010**, *60*, 1810–1814. [CrossRef] [PubMed]
39. Oehlmann, J.; Schulte-Oehlmann, U.; Kloas, W.; Jagnytsch, O.; Lutz, I.; Kusk, K.O.; Wollenberger, L.; Santos, E.M.; Paull, G.C.; Van Look, K.J.; et al. A critical analysis of the biological impacts of plasticizers on wildlife. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **2009**, *364*, 2047–2062. [CrossRef]
40. Teuten, E.L.; Saquing, J.M.; Knappe, D.R.; Barlaz, M.A.; Jonsson, S.; Björn, A.; Rowland, S.J.; Thompson, R.C.; Galloway, T.S.; Yamashita, R.; et al. Transport and release of chemicals from plastics to the environment and to wildlife. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **2009**, *364*, 2027–2045. [CrossRef] [PubMed]
41. Gregory, M.R. Environmental implications of plastic debris in marine settings—Entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philos. Trans. R. Soc. B Biol. Sci.* **2009**, *364*, 2013–2025. [CrossRef] [PubMed]
42. Lin, V.S. Research highlights: Impacts of microplastics on plankton. *Environ. Sci. Process Impacts* **2016**, *18*, 160–163. [CrossRef]
43. Mao, Y.; Ai, H.; Chen, Y.; Zhang, Z.; Zeng, P.; Kang, L.; Li, W.; Gu, W.; He, Q.; Li, H. Phytoplankton response to polystyrene microplastics: Perspective from an entire growth period. *Chemosphere* **2018**, *208*, 59–68. [CrossRef]
44. Wu, Y.; Guo, P.; Zhang, X.; Zhang, Y.; Xie, S.; Deng, J. Effect of microplastics exposure on the photosynthesis system of freshwater algae. *J. Hazard. Mater.* **2019**, *374*, 219–227. [CrossRef]
45. Cao, Q.; Sun, W.; Yang, T.; Zhu, Z.; Jiang, Y.; Hu, W.; Wei, W.; Zhang, Y.; Yang, H. The toxic effects of polystyrene microplastics on freshwater algae *Chlorella pyrenoidosa* depends on the different size of polystyrene microplastics. *Chemosphere* **2022**, *308*, 136135. [CrossRef]
46. Fu, D.; Zhang, Q.; Fan, Z.; Qi, H.; Wang, Z.; Peng, L. Aged microplastics polyvinyl chloride interact with copper and cause oxidative stress towards microalgae Chlorella vulgaris. *Aquat. Toxicol.* **2019**, *216*, 105319. [CrossRef] [PubMed]
47. Zhou, J.; Gao, L.; Lin, Y.; Pan, B.; Li, M. Micrometer scale polystyrene plastics of varying concentrations and particle sizes inhibit growth and upregulate microcystin-related gene expression in *Microcystis aeruginosa*. *J. Hazard. Mater.* **2021**, *420*, 126591. [CrossRef]
48. Bhattacharya, A.; Khare, S.K. Ecological and toxicological manifestations of microplastics: Current scenario, research gaps, and possible alleviation measures. *J. Environ. Sci. Health Part C* **2022**, *38*, 1–20. [CrossRef]
49. Chen, X.; Chen, X.; Zhao, Y.; Zhou, H.; Xiong, X.; Wu, C. Effects of microplastic biofilms on nutrient cycling in simulated freshwater systems. *Sci. Total Environ.* **2020**, *719*, 137276. [CrossRef]
50. Hitchcock, J.N. Microplastics can alter phytoplankton community composition. *Sci. Total Environ.* **2022**, *819*, 153074. [CrossRef] [PubMed]

51. Ali, W.; Das, S.; Thery, J.; Jeong, H.; Lee, J.S.; Zinck, P.; Souissi, S. Acute and multigenerational toxicity of polylactic acid microplastics on a copepod bioindicator. *Environ. Chem. Lett.* **2024**, *22*, 2167–2175. [CrossRef]
52. Yu, S.P.Y.; Cole, M.C.; Chan, B.K. Effects of Microplastic on Zooplankton Survival and Sublethal Responses. In *Oceanography and Marine Biology*; CRC Press: Boca Raton, FL, USA, 2020.
53. Sánchez-Zamora, C.; Nandini, S.; Sarma, S.S.S. Synergistic effects of microplastics and cyanotoxins on the demography of the rotifer *Brachionus calyciflorus* Pallas. *Chemosphere* **2024**, *365*, 143355. [CrossRef]
54. Leiser, R.; Wu, G.M.; Neu, T.R.; Wendt-Potthoff, K. Biofouling, metal sorption and aggregation are related to sinking of microplastics in a stratified reservoir. *Water Res.* **2020**, *176*, 115748. [CrossRef] [PubMed]
55. Vercauteren, M.; Lambert, S.; Hoogerwerf, E.; Janssen, C.R.; Asselman, J. Microplastic-specific biofilm growth determines the vertical transport of plastics in freshwater. *Sci. Total Environ.* **2024**, *910*, 168399. [CrossRef] [PubMed]
56. Joseph, S.J.P.; Subramani, N. Advancing sustainability: The role of epiplastic microalgae and their enzymatic pathways in freshwater plastic biodegradation. *J. Water Process Eng.* **2024**, *67*, 106134.
57. Amaneesh, C.; Anna Balan, S.; Silpa, P.S.; Kim, J.W.; Greeshma, K.; Aswathi Mohan, A.; Robert Antony, A.; Grossart, H.P.; Kim, H.S.; Ramanan, R. Gross negligence: Impacts of microplastics and plastic leachates on phytoplankton community and ecosystem dynamics. *Environ. Sci. Technol.* **2022**, *57*, 5–24. [CrossRef]
58. Ge, J.; Li, H.; Liu, P.; Zhang, Z.; Ouyang, Z.; Guo, X. Review of the toxic effect of microplastics on terrestrial and aquatic plants. *Sci. Total Environ.* **2021**, *791*, 148333. [CrossRef]
59. Ceschin, S.; Mariani, F.; Di Lernia, D.; Venditti, I.; Pelella, E.; Iannelli, M.A. Effects of microplastic contamination on the aquatic plant Lemna minuta (least duckweed). *Plants* **2023**, *12*, 207. [CrossRef] [PubMed]
60. Silva, C.J.; Machado, A.L.; Campos, D.; Rodrigues, A.C.; Silva, A.L.P.; Soares, A.M.; Pestana, J.L. Microplastics in freshwater sediments: Effects on benthic invertebrate communities and ecosystem functioning assessed in artificial streams. *Sci. Total Environ.* **2022**, *804*, 150118. [CrossRef] [PubMed]
61. Berlino, M.; Mangano, M.C.; De Vittor, C.; Sarà, G.J.E.P. Effects of microplastics on the functional traits of aquatic benthic organisms: A global-scale meta-analysis. *Environ. Pollut.* **2021**, *285*, 117174. [CrossRef] [PubMed]
62. Prata, J.C.; Silva, C.J.; Serpa, D.; Soares, A.M.; Gravato, C.; Silva, A.L.P. Mechanisms influencing the impact of microplastics on freshwater benthic invertebrates: Uptake dynamics and adverse effects on *Chironomus riparius*. *Sci. Total Environ.* **2023**, *859*, 160426. [CrossRef] [PubMed]
63. D'Costa, A.H. Microplastics in decapod crustaceans: Accumulation, toxicity and impacts, a review. *Sci. Total Environ.* **2022**, *832*, 154963. [CrossRef] [PubMed]
64. Yin, J.; Li, J.Y.; Craig, N.J.; Su, L. Microplastic pollution in wild populations of decapod crustaceans: A review. *Chemosphere* **2022**, *291*, 132985. [CrossRef] [PubMed]
65. Weber, A.; Jeckel, N.; Weil, C.; Umbach, S.; Brennholt, N.; Reifferscheid, G.; Wagner, M. Ingestion and toxicity of polystyrene microplastics in freshwater bivalves. *Environ. Toxicol. Chem.* **2021**, *40*, 2247–2260. [CrossRef]
66. Jeyavani, J.; Sibiya, A.; Gopi, N.; Mahboob, S.; Riaz, M.N.; Vaseeharan, B. Dietary consumption of polypropylene microplastics alter the biochemical parameters and histological response in freshwater benthic mollusc Pomaceapaludosa. *Environ. Res.* **2022**, *212*, 113370. [CrossRef] [PubMed]
67. Rodrigues, C.C.; Harayashiki, C.A.; Pereira, E.S.; Rodrigues, G.L.; Neves, B.J.; Rocha, T.L. How do microplastics alter molluscicidal activity? Effects of weathered microplastics and niclosamide in developing freshwater snails. *Sci. Total Environ.* **2024**, *922*, 171165. [CrossRef]
68. Scherer, C.; Weber, A.; Lambert, S.; Wagner, M. *Interactions of Microplastics with Freshwater Biota*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 153–180.
69. Nodehi, R.N.; Hadi, M.; Hosseinzadeh, A.; Azizi, N. Comprehensive systematic review and meta-analysis of microplastic prevalence and abundance in freshwater fish species: The effect of fish species habitat, feeding behavior, and Fulton's condition factor. *J. Environ. Health Sci. Eng.* **2024**, *22*, 365–380. [CrossRef]
70. Pazos, R.S.; Maiztegui, T.; Colautti, D.C.; Paracampo, A.H.; Gómez, N. Microplastics in gut contents of coastal freshwater fish from Río de la Plata estuary. *Mar. Pollut. Bull.* **2017**, *122*, 85–90. [CrossRef] [PubMed]
71. McNeish, R.E.; Kim, L.H.; Barrett, H.A.; Mason, S.A.; Kelly, J.J.; Hoellein, T.J. Microplastic in riverine fish is connected to species traits. *Sci. Rep.* **2018**, *8*, 11639. [CrossRef] [PubMed]
72. Azevedo-Santos, V.M.; Goncalves, G.R.; Manoel, P.S.; Andrade, M.C.; Lima, F.P.; Pelicice, F.M. Plastic ingestion by fish: A global assessment (Barking, Essex: 1987). *Environ. Pollut.* **2019**, *25 Pt 1*, 112994. [CrossRef]
73. Sulaiman, B.; Woodward, J.C.; Shiels, H.A. Riverine microplastics and their interaction with freshwater fish. *Water Biol. Secur.* **2023**, *2*, 100192. [CrossRef]
74. Roch, S.; Friedrich, C.; Brinker, A. Uptake routes of microplastics in fishes: Practical and theoretical approaches to test existing theories. *Sci. Rep.* **2020**, *10*, 3896. [CrossRef] [PubMed]

75. Yadav, D.K.; Samantaray, B.P.; Kumar, R. Effect of alternative natural diet on microplastic ingestion, functional responses and trophic transfer in a tri-trophic coastal pelagic food web. *Sci. Total Environ.* **2024**, *950*, 174999. [CrossRef] [PubMed]
76. Roch, S.; Rebl, A.; Wolski, W.; Brinker, A. Combined proteomic and gene expression analysis to investigate reduced performance in rainbow trout (*Oncorhynchus mykiss*) caused by environmentally relevant microplastic exposure. *Microplast. Nanoplast.* **2022**, *2*, 14. [CrossRef]
77. Lambert, S.; Wagner, M. *Microplastics are Contaminants of Emerging Concern in Freshwater Environments: An Overview*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 1–23.
78. Lin, L.; Ma, L.S.; Li, H.X.; Pan, Y.F.; Liu, S.; Zhang, L.; Peng, J.P.; Fok, L.; Xu, X.R.; He, W.H. Low level of microplastic contamination in wild fish from an urban estuary. *Mar. Pollut. Bulletin.* **2020**, *160*, 111650. [CrossRef] [PubMed]
79. Mallik, A.; Xavier, K.M.; Naidu, B.C.; Nayak, B.B. Ecotoxicological and physiological risks of microplastics on fish and their possible mitigation measures. *Sci. Total Environ.* **2021**, *779*, 146433. [CrossRef] [PubMed]
80. Ismail, M.R.; Lewaru, M.W.; Prihadi, D.J. Microplastics Ingestion by fish in the Biawak Island. *World Sci. News* **2018**, *106*, 230–237.
81. Adeogun, A.O.; Ibor, O.R.; Khan, E.A.; Chukwuka, A.V.; Omogbemi, E.D.; Arukwe, A. Detection and occurrence of microplastics in the stomach of commercial fish species from a municipal water supply lake in southwestern Nigeria. *Environ. Sci. Pollut. Res.* **2020**, *27*, 31035–31045. [CrossRef] [PubMed]
82. Wang, S.; Zhang, C.; Pan, Z.; Sun, D.; Zhou, A.; Xie, S.; Wang, J.; Zou, J. Microplastics in wild freshwater fish of different feeding habits from Beijiang and Pearl River Delta regions, south China. *Chemosphere* **2020**, *258*, 127345. [CrossRef] [PubMed]
83. Ferreira, G.V.; Barletta, M.; Lima, A.R.; Dantas, D.V.; Justino, A.K.; Costa, M.F. Plastic debris contamination in the life cycle of Acoupa weakfish (Cynoscionacoupa) in a tropical estuary. *ICES J. Mar. Sci.* **2016**, *73*, 2695–2707. [CrossRef]
84. Kibria, G. Impacts of microplastic on fisheries and seafood security—Global analysis and synthesis. *Sci. Total Environ.* **2023**, *904*, 166652. [CrossRef] [PubMed]
85. Parvin, F.; Jannat, S.; Tareq, S.M. Abundance, characteristics and variation of microplastics in different freshwater fish species from Bangladesh. *Sci. Total Environ.* **2021**, *784*, 147137. [CrossRef] [PubMed]
86. Ding, J.; Huang, Y.; Liu, S.; Zhang, S.; Zou, H.; Wang, Z.; Zhu, W.; Geng, J. Toxicological effects of nano-and micro-polystyrene plastics on red tilapia: Are larger plastic particles more harmless? *J. Hazard. Mater.* **2020**, *396*, 122693. [CrossRef] [PubMed]
87. Ding, J.; Zhang, S.; Razanajatovo, R.M.; Zou, H.; Zhu, W. Accumulation, tissue distribution, and biochemical effects of polystyrene microplastics in the freshwater fish red tilapia (*Oreochromis niloticus*). *Environ. Pollut.* **2018**, *238*, 1–9. [CrossRef] [PubMed]
88. Lu, Y.; Zhang, Y.; Deng, Y.; Jiang, W.; Zhao, Y.; Geng, J.; Ding, L.; Ren, H. Uptake and accumulation of polystyrene microplastics in zebra fish (*Danio rerio*) and toxic effects in liver. *Environ. Sci. Technol.* **2016**, *50*, 4054–4060. [CrossRef]
89. Karami, A.; Romano, N.; Galloway, T.; Hamzah, H. Virgin microplastics cause toxicity and modulate the impacts of phenanthrene on biomarker responses in African catfish (*Clarias gariepinus*). *Environ. Res.* **2016**, *151*, 58–70. [CrossRef]
90. Michailidou, K.; Palisidou, C.; Feidantsis, K.; Ainali, N.M.; Kastrinaki, G.; Lambropoulou, D.A.; Kyzas, G.Z.; Bikiaris, D.N.; Kaloyianni, M.; Bobori, D.C. Impact of aged and virgin polyethylene microplastics on multi end-points effects of freshwater fish tissues. *Sci. Total Environ.* **2024**, *948*, 174704. [CrossRef] [PubMed]
91. Ding, P.; Xiang, C.; Li, X.; Chen, H.; Shi, X.; Li, X.; Huang, C.; Yu, Y.; Qi, J.; Li, A.J.; et al. Photoaged microplastics induce neurotoxicity via oxidative stress and abnormal neurotransmission in zebrafish larvae (Danio rerio). *Sci. Total Environ.* **2023**, *881*, 163480. [CrossRef]
92. Lithner, D.; Damberg, J.; Dave, G.; Larsson, Å. Leachates from plastic consumer products—Screening for toxicity with Daphnia magna. *Chemosphere* **2009**, *74*, 1195–1200. [CrossRef]
93. Lithner, D.; Larsson, A.; Dave, G. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. *Sci. Total Environ.* **2011**, *409*, 3309–3324. [CrossRef] [PubMed]
94. Parker, B.; Andreou, D.; Green, I.D.; Britton, J.R. Microplastics in freshwater fishes: Occurrence, impacts and future perspectives. *Fish Fish.* **2021**, *22*, 467–488. [CrossRef]
95. Pohnert, G.; Steinke, M.; Tollrian, R. Chemical cues, defence metabolites and the shaping of pelagic interspecific interactions. *Trends Ecol. Evol.* **2007**, *22*, 198–204. [CrossRef] [PubMed]
96. Lürling, M.; Scheffer, M. Info-disruption: Pollution and the transfer of chemical information between organisms. *Trends Ecol. Evol.* **2007**, *22*, 374–379. [CrossRef] [PubMed]
97. Besseling, E.; Wang, B.; Lurling, M.; Koelmans, A.A. Nanoplastic affects growth of S. obliquus and reproduction of *D. magna*. *Environ. Sci. Technol.* **2014**, *48*, 12336–12343. [CrossRef] [PubMed]
98. Sjollema, S.B.; Redondo-Hasselerharm, P.; Leslie, H.A.; Kraak, M.H.; Vethaak, A.D. Do plastic particles affect microalgal photosynthesis and growth? *Aquat. Toxicol.* **2016**, *170*, 259–261. [CrossRef] [PubMed]
99. Cole, M.; Lindeque, P.K.; Fileman, E.; Clark, J.; Lewis, C.; Halsband, C.; Galloway, T.S. Microplastics alter the properties and sinking rates of zooplankton faecal pellets. *Environ. Sci. Technol.* **2016**, *50*, 3239–3246. [CrossRef] [PubMed]
100. Carson, H.S.; Colbert, S.L.; Kaylor, M.J.; McDermid, K.J. Small plastic debris changes water movement and heat transfer through beach sediments. *Mar. Pollut. Bull.* **2011**, *62*, 1708–1713. [CrossRef]

101. Wang, L.; Nabi, G.; Yin, L.; Wang, Y.; Li, S.; Hao, Z.; Li, D. Birds and plastic pollution: Recent advances. *Avian Res.* **2021**, *12*, 59. [CrossRef] [PubMed]
102. Gallitelli, L.; Cera, A.; Scalici, M.; Sodo, A.; Di Gioacchino, M.; Luzi, B.; Hortas, F.; Green, A.J.; Coccia, C. Plastic ingestion in aquatic insects: Implications of waterbirds and landfills and association with stable isotopes. *Sci. Total Environ.* **2024**, *954*, 176707. [CrossRef] [PubMed]
103. Bilal, M.; Yaqub, A.; Hassan, H.U.; Akhtar, S.; Rafiq, N.; Ali Shah, M.I.; Hussain, I.; Salman Khan, M.; Nawaz, A.; Manoharadas, S.; et al. Microplastic Quantification in Aquatic Birds: Biomonitoring the Environmental Health of the Panjkora River Freshwater Ecosystem in Pakistan. *Toxics* **2023**, *11*, 972. [CrossRef] [PubMed]
104. Hoang, T.C.; Mitten, S. Microplastic accumulation in the gastrointestinal tracts of nestling and adult migratory birds. *Sci. Total Environ.* **2022**, *838*, 155827. [CrossRef]
105. Clause, A.G.; Celestian, A.J.; Pauly, G.B. Plastic ingestion by freshwater turtles: A review and call to action. *Sci. Rep.* **2021**, *11*, 5672. [CrossRef]
106. Gao, S.; Zhang, S.; Sun, J.; He, X.; Xue, S.; Zhang, W.; Li, P.; Lin, L.; Qu, Y.; Ward-Fear, G.; et al. Nanoplastic pollution changes the intestinal microbiome but not the morphology or behavior of a freshwater turtle. *Sci. Total Environ.* **2024**, *934*, 173178. [CrossRef] [PubMed]
107. Blettler, M.C.; Mitchell, C. Dangerous traps: Macroplastic encounters affecting freshwater and terrestrial wildlife. *Sci. Total Environ.* **2021**, *798*, 149317. [CrossRef] [PubMed]
108. Roman, L.; Hardesty, B.D.; Schuyler, Q. A systematic review and risk matrix of plastic litter impacts on aquatic wildlife: A case study of the Mekong and Ganges River Basins. *Sci. Total Environ.* **2022**, *843*, 156858. [CrossRef]
109. Chen, Q.; Allgeier, A.; Yin, D.; Hollert, H. Leaching of endocrine disrupting chemicals from marine microplastics and mesoplastics under common life stress conditions. *Environ. Int.* **2019**, *130*, 104938. [CrossRef] [PubMed]
110. Saha, U.; Kumari, P.; Ghosh, A.; Sinha, A.; Jena, S.; Kirti, A.; Gupta, A.; Choudhury, A.; Simnani, F.Z.; Nandi, A.; et al. Detrimental consequences of micropolymers associated plasticizers on endocrinal disruption. *Mater. Today Bio* **2024**, *27*, 101139. [CrossRef]
111. Park, J.H.; Hong, S.; Kim, O.H.; Kim, C.H.; Kim, J.; Kim, J.W.; Hong, S.; Lee, H.J. Polypropylene microplastics promote metastatic features in human breast cancer. *Sci. Rep.* **2023**, *13*, 6252. [CrossRef]
112. Segovia-Mendoza, M.; Nava-Castro, K.E.; Palacios-Arreola, M.I.; Garay-Canales, C.; Morales-Montor, J. How microplastic components influence the immune system and impact on children health: Focus on cancer. *Birth Defects Res.* **2020**, *112*, 1341–1361. [CrossRef] [PubMed]
113. Yang, Z.; Wang, M.; Feng, Z.; Wang, Z.; LV, M.; Chang, J.; Chen, L.; Wang, C. Human microplastics exposure and potential health risks to target organs by different routes: A review. *Curr. Pollut. Rep.* **2023**, *9*, 468–485. [CrossRef]
114. Zurub, R.E.; Cariaco, Y.; Wade, M.G.; Bainbridge, S.A. Microplastics exposure: Implications for human fertility, pregnancy and child health. *Front. Endocrinol.* **2024**, *14*, 1330396. [CrossRef]
115. Kadac-Czapska, K.; Trzebiatowska, P.J.; Mazurkiewicz, M.; Kowalczyk, P.; Knez, E.; Behrendt, M.; Mahlik, S.; Zaleska-Medynska, A.; Grembecka, M. Isolation and identification of microplastics in infant formulas—A potential health risk for children. *Food Chem.* **2024**, *440*, 138246. [CrossRef] [PubMed]
116. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made. *Sci. Adv.* **2017**, *3*, e1700782. [CrossRef] [PubMed]
117. Xu, Z.; Bai, X.; Ye, Z. Removal and generation of microplastics in wastewater treatment plants: A review. *J. Clean. Prod.* **2021**, *291*, 125982. [CrossRef]
118. Garfansa, M.P.; Zalizar, L.; Husen, S.; Triwanto, J.; Ramadani, S.D.; Iswahyudi, I.; Ekalaturrahmah, Y.A.C. Research and Trends of Filtration for Removing Microplastics in Freshwater Environments. *Environ. Qual. Manag.* **2024**, *34*, e22301. [CrossRef]
119. Bexeitova, K.; Baimenov, A.; Varol, E.A.; Kudaibergenov, K.; Zhantikeyev, U.; Sailaukhanuly, Y.; Toshtay, K.; Tauanov, Z.; Azat, S.; Berndtsson, R. Microplastics in freshwater systems: A review of classification, sources, and environmental impacts. *Chem. Eng. J. Adv.* **2024**, *20*, 100649. [CrossRef]
120. Prata, J.C.; Silva, A.L.P.; da Costa, J.P.; Mouneyrac, C.; Walker, T.R.; Duarte, A.C.; Rocha-Santos, T. Solutions and integrated strategies for the control and mitigation of plastic and microplastic pollution. *Int. J. Environ. Res. Public Health* **2019**, *16*, 2411. [CrossRef]
121. Mitrano, D.M.; Wohlleben, W. Microplastic regulation should be more precise to incentivize both innovation and environmental safety. *Nat. Commun.* **2020**, *11*, 5324. [CrossRef] [PubMed]