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*Review*

# An Overview on Microplastics Hazards to the Marine Ecosystem and Humans' Health

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**Abstract:** Microplastic contamination is rapidly becoming an increasingly worrying environmental problem and poses a real threat to marine ecosystems and human health. The aim of this research was to conduct a traditional review of the current state of the art regarding the sources of MPs in marine environment, including an assessment of their toxic effect on marine organisms and transfer within the food webs and up to humans. An extensive literature search (from 1 January 2024 to 15 February 2025) yielded a total of 1027 primary research articles on this topic. This overview revealed that MPs can be ingested by marine organisms, migrate through the intestinal wall, and spread to other organs. They can biomagnify along the food chain and can be carriers of toxic chemicals and pathogen agents. Exposure of marine organisms to MPs can lead to several risks, including tissue damage, oxidative stress, and changes in immune-related gene expression, neurotoxicity, growth retardation, and behavioural abnormalities. The toxicity of MPs depends mainly on the particle size distribution and composition/characteristics of the polymer. The main routes of human exposure to MPs have been identified as ingestion (mainly seafood), inhalation, and dermal exposure. There is strong evidence of contamination of seafood by MPs, which pose a potential risk to human health. This study provides the basis for assessing MPs' risk to marine ecosystems and potential human health impacts.

**Keywords:** plastic pollution; microplastics; marine organisms; human health



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## 1. Introduction

Plastics play a fundamental role in our society; their unique properties allow them to be used in a wide range of applications and meet the needs of many industries. Currently, production and consumption follow an exponential trend that brought plastic materials to become one of the largest contributors to global waste. Global plastics production is predicted to continue to grow in the coming years, reaching around 1.2 billion tonnes in 2060. At the same time, plastic waste management will become a growing concern, with around 250 million tonnes expected to be generated by 2025 [1].

Globally, only 9% of all the plastic waste, is recycled, while 19% is incinerated, 49% is landfilled, and 22% is mismanaged, accumulating in natural environments and ending up in seas and oceans [2].

The increasing presence of plastic litter in the environment and efforts to reduce its pollution have become one of the most serious environmental challenges, among scientists and policy makers. Recently, the United Nations Environment Assembly (UNEA) requested the Executive Director of UNEP to develop an international legally binding instrument on plastic pollution, including in the marine environment, based on a global approach that addresses the entire life cycle of plastics [3].

They are considered persistent contaminants due to their slow degradation, but plastics can undergo fragmentation into progressively smaller pieces, known as 'microplastics' (0.1 µm–5 mm) and "nanoplastics" (<0.1 µm), most of which are expected to persist in the environment in some form over geological timescales [4]. Microplastics in the environment come from a variety of sources and pose several hidden dangers. Understanding their toxic effects and potential risks to human health is therefore a major challenge.

The sea and ocean are the ultimate repository of these particles [5], and their presence is causing growing concern about their potential impact on marine life and human well-being. Plastics and MPs are ubiquitous in all environmental compartments, from beaches to the seabed, in sediments, in the water column, and even in remote areas such as the Arctic and Antarctic [6].

The small size of MPs makes this debris untraceable to its source and difficult to remove from the marine environment, meaning that the most effective reduction strategies must involve reducing inputs [7].

It is well known that coastal marine areas provide ecosystem services of high economic value for both human well-being and for vertebrate and invertebrate organisms. Unfortunately, as a result of inappropriate waste management, the accumulation of plastic waste in these areas is very abundant, with negative effects on ecological aspects, including biodiversity, economic activities, and humans [8,9]. For marine users and coastal communities, plastic debris leads to income losses and increased costs [10].

The presence of plastic has the potential to dramatically alter the ecology of marine systems [11]. Changes in biodiversity can have potentially far-reaching and unpredictable side effects on society, such as a reduction in the resilience and recovery potential of ecosystems.

Eliminating or at least reducing the negative impacts will require a global transition with implications for public behaviour, legislation and governance, and industry and trade [12].

This article aims to provide an overview of the hazards of microplastics on marine organisms and focuses on a multidisciplinary approach, drawing on environmental, toxicological, and public health sciences. It examines how different types of microplastics interact with different marine organisms and the implications for human health.

## 2. Literature Review Search Methodology

Deep systematic research of literature was carried out to assess the current state of the art of MPs in the marine environment (sources, sinks, marine plastic waste); to examine the toxicity of MPs to marine organisms; and to assess the potential risk to human health issues.

Search restrictions were placed on English articles published from 1 January 2024 to 15 February 2025 from the database Scopus (www.scopus.com (accessed on 15 February 2025)). The search was performed using the searching string of TITLE-ABS-KEY on the topic "microplastic" OR "microplastics" AND "toxicity" AND "marine organisms" AND "human health; "bioplastic OR bioplastics" AND "toxicity" AND marine organisms" AND "human health".

The initial search led to 2518 documents of potentially relevant studies. After eliminating review articles ($n$ = 811), a total of n = 1588 research articles were attained. After removal of duplicates and further rigorous screening through the title and abstract in a first step and full paper reading in a second step, studies that were irrelevant to the selected topics were excluded, reducing the number of eligible documents to 1027. The 1027 studies were published in 184 international peer-reviewed journals, of which 34 journals have published at least 3 articles on the topic of the present review. In particular, the following journals have published more than thirty articles during the selected period, showing a particular attention for this topic: *Journal of Hazardous Materials*, *Environmental Pollution*, *Chemosphere*, *Marine Pollution Bulletin*, and *Ecotoxicology and Environmental Safety* (Figure 1A).

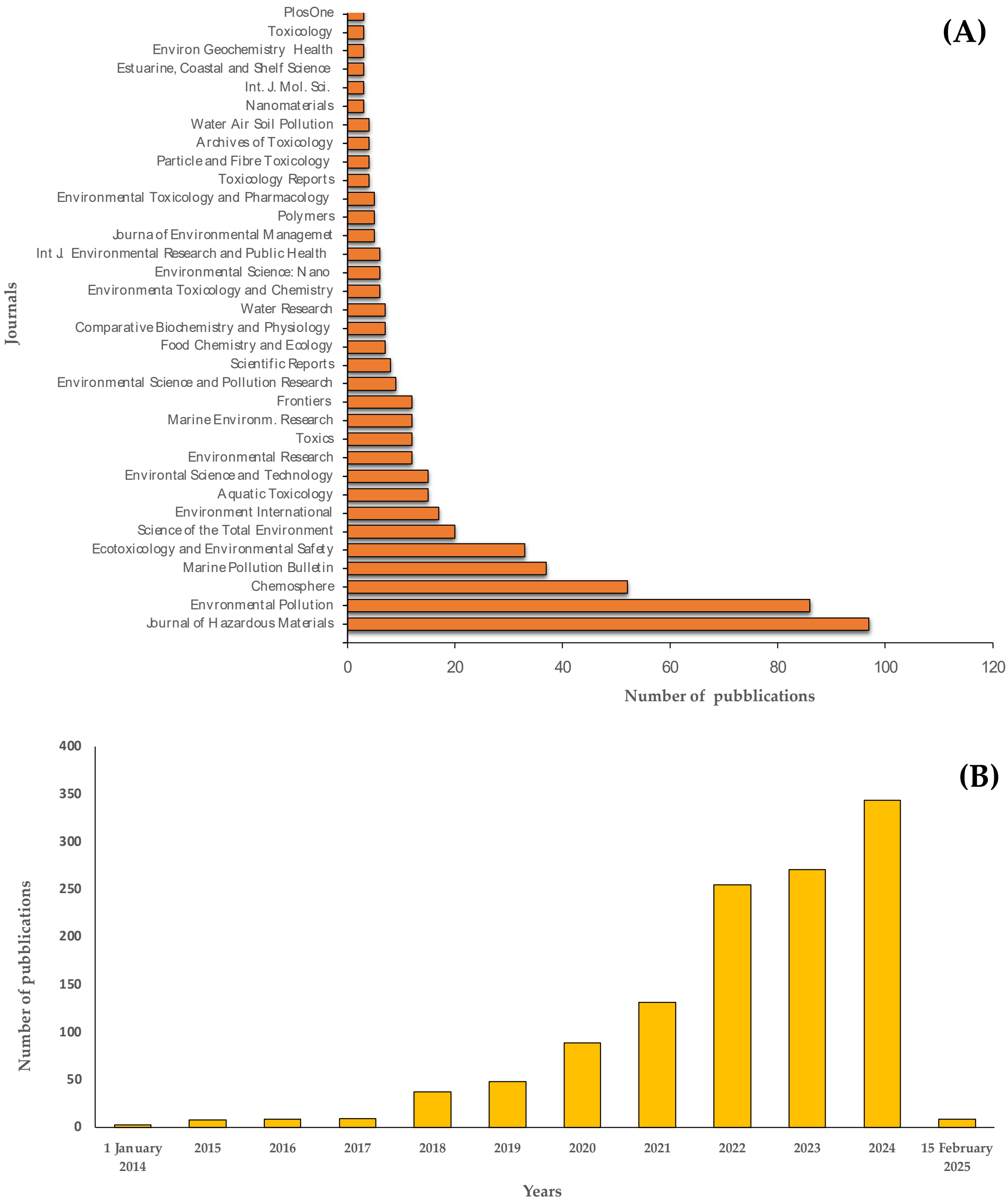


**Figure 1.** Number of publications found from individual journals (**A**) and by year (**B**). Journals that have published almost three articles are included in Figure 1A. Articles published from 1 January 2024 to 15 February 2015 are included in Figure 1B.

Figure 1B shows a marked increase in the number of publications per year on this topic since 2014, indicating an increase in attention from researchers and academics, leading to more research efforts in recent years.

In order to illustrate the dominant research themes in the selected articles, we used a visualisation method that highlights the most frequently used words, represented by the largest size. To achieve this, all words in the titles of the selected articles were sorted in descending order of frequency of use. The data were entered into word clouds (www.wordclouds.com (accessed on 17 February 2025)), which are shown in Figure 2. Keywords such as microplastics, toxicity, risk, and marine and human health are the most frequently found words in the selected literature.

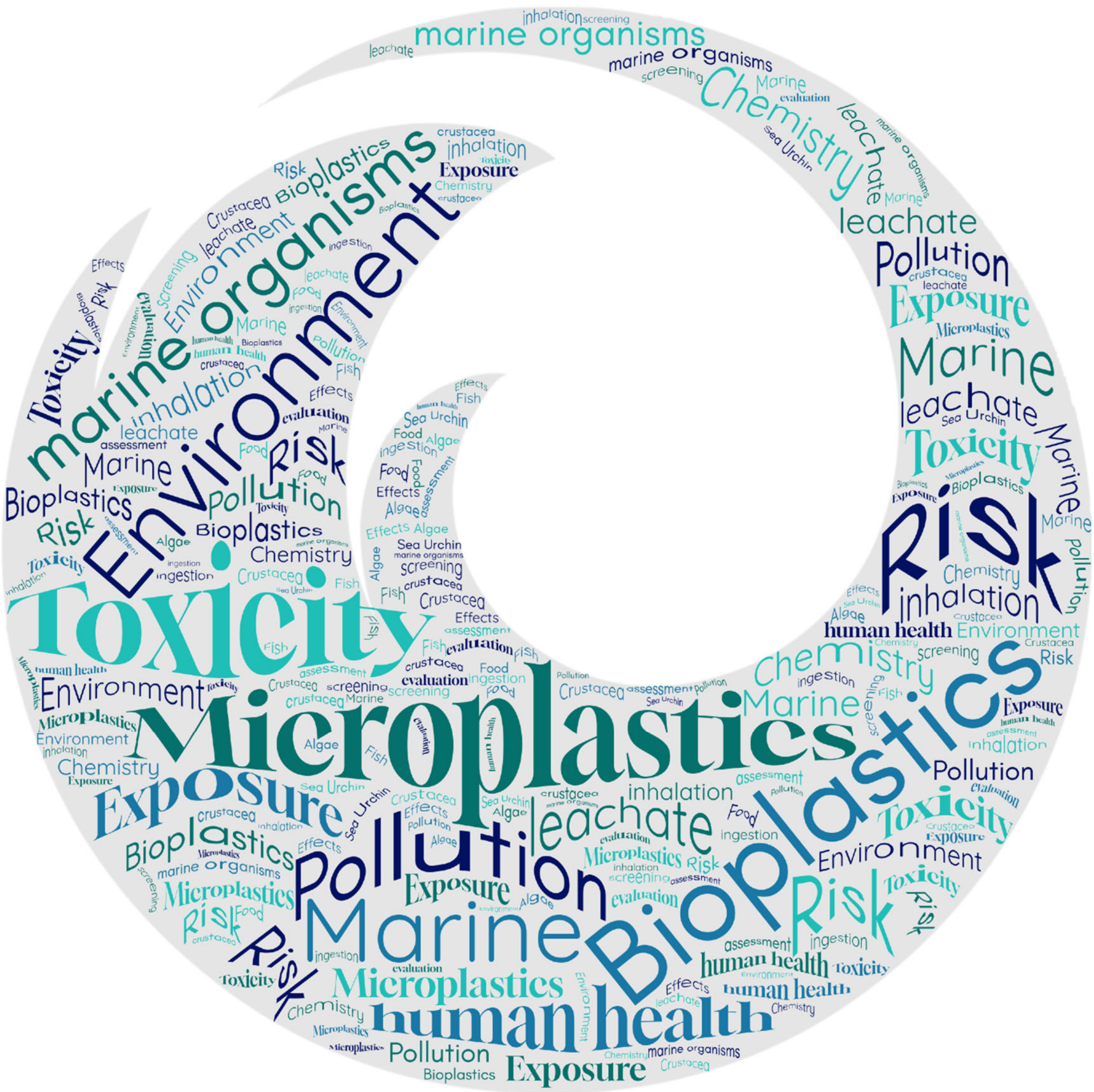


**Figure 2.** Word clouds computed from the titles of the selected 1027 articles in this review.

Figure 3 shows the percentages of articles reporting the groups of taxa used in the MP ecotoxicological assessments. The results show that molluscs have received the most attention (30%), followed by fish (24%).

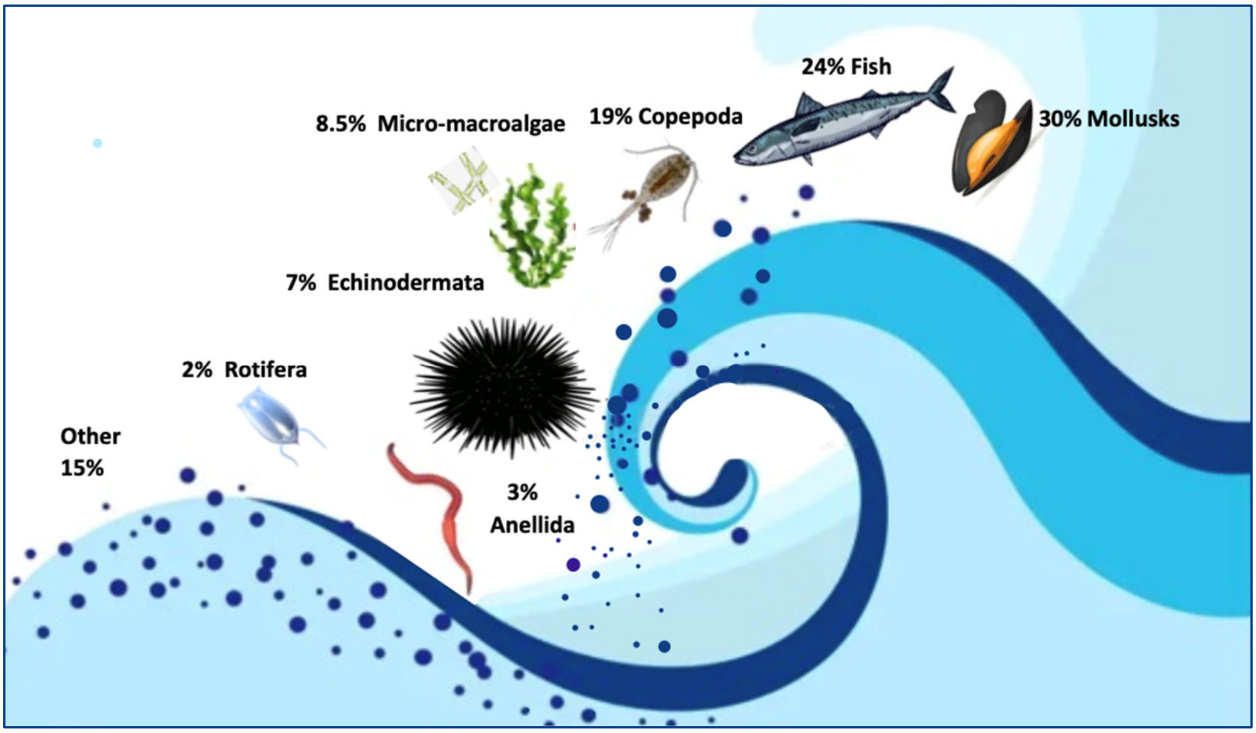


**Figure 3.** Articles percentage on MPs ecotoxicological evaluation by using marine organisms.

## 3. Plastics Polymer: Types and Physical–Chemical Characteristics

### 3.1. Plastic Types

The "plastic" name does not refer to a single material but covers a wide range of materials with very different characteristics and manufacturing processes. For this reason, understanding the impact of plastics is difficult and complex due to their different physical and chemical characteristics that make them multifaceted stressors.

Conventional plastics are made from non-renewable resources, such as gas or petroleum. The Society of the Plastic Industry (SPI) has established a numerical coding system for these plastics, assigning numbers from 1 to 7 to different types.

Number 1 for polyethylene terephthalate (PET), 2 for High-Density Polyethylene (HDPE), 3 for Polyvinil chloride (PVC), 4 for low-density polyethylene (LDPE), 5 for Polypropylene (PP), 6 for Polystyrene (PS), and 7 for other plastic polymers, such as nylon fibres, feeding bottles, compact discs, containers for medical use, car parts, etc. [13,14].

It is widely recognised that society needs to move towards sustainability and to meet the increasing demand for plastic materials from a growing world population, while protecting ecosystems. This means promoting the use of sustainable polymers that have similar properties to traditional non-biodegradable petroleum-based plastics and can be produced and disposed in harmony with the environment.

Bioplastics are being promoted as safer alternatives, as they are either bio-based, biodegradable, or both [15]. Bio-based means a material or product is made from biomass that comes from sources like corn, sugar cane, wood, potatoes, vegetable oils, and food waste. Their biodegradation is a biochemical process that leads to breakdown of materials through a physical or chemical change that occurs by the mineralization to $CO_2$, biomass, and water through biological activities [15].

In Europe, bioplastics account for around 1% of total plastic demand and are set to grow, although they are expected to increase from around 2.23 million tonnes in 2022 to around 6.3 million tonnes in 2027 [16]. The cost comes from factors such as raw material sourcing and processing. Furthermore, large-scale production of bioplastics requires significant investments in infrastructure and technology. As a result, nowadays, their adoption remains limited.

### 3.2. Microplastics: Size, Shape, and Density

Although plastic is recognised to be an inert material, it has a complex variety of physical–chemical characteristics (i.e., size, shape, density, polymer type, polymer chemical composition) [17].

Based on particle size, polymers can be classified as follows: macroplastics (>25 mm), mesoplastics (5–25 mm), microplastics (<5 mm), and nanoplastics (<0.1 μm).

Moreover, they can be classified according to their original manufactured size in primary MPs and secondary MPs. Primary MPs are those intentionally produced by the industry in different shapes (fragments, fibres, spheres, granules, pellets, flakes, or beads) and size, depending on their final use [17,18]. They are added to various products (medical devices, pharmaceuticals, electronic devices, fertilisers, cosmetics, detergents, toothpastes, paints) for their abrasive, exfoliating, and smoothing properties or to maintain the thickness, appearance, and stability of the product.

Secondary MPs are those that result from the fragmentation/degradation of macroplastics already present in the environment as waste. The degradation and fragmentation of plastic litter in the environment is caused by abiotic and biotic factors, such as chemical (i.e., photolysis, hydrolysis, and thermal), mechanical (abrasion caused by wind, waves), and biological reactions (e.g., bacteria and fungi) [19]. This fragmentation can determine the production of different plastics shape: fibres, fragments, films.

Density is another important physical property of microplastics, generally associated with the distribution and mobility of MPs in the aquatic environment, for example, low-density MPs such as PE and PP float in water, while high-density microplastics tend to sink to sediment [20].

### 3.3. Addittives

Additives are intentionally added to both conventional and bio-based plastics during the manufacturing process in order to achieve desired material properties such as flexibility, heat/flame resistance, durability, colour, etc., depending on the application.

Additives are not covalently bound to polymeric material, so they can be easily leached out of the finished product under favourable conditions. The most frequent additives found in the environment are bisphenols, phthalates, nonylphenols, and brominated flame retardants (BFRs) [21]. The high heat and other stresses of the manufacturing process often generate additional leachable 'degradation chemicals' that may have estrogenic activity. Therefore, long-term plastic exposure can inevitably lead to the leaching of many harmful substances that can be transferred to marine organisms and humans [22,23].

Some of these chemicals are known as endocrine-disrupting chemicals (EDCs), substances that have negative effects on the environment and wildlife and often impact human health [24,25]. The most commonly used additive with estrogenic activity (EA) is bisphenol A (BPA). It is commonly used as plasticizer in the plastics industry, more specifically in the manufacture of polycarbonate plastics and food packaging [24]. It is found in many environmental compartments, including the aquatic environment, where it enters via point source discharges, such as landfill leachate and sewage treatment plant effluents. BPA was considered an EDC, and for that reason, it was banned and phased out of plastic products in many countries. Alternative chemicals, such as bisphenol S (BPS) and bisphenol F (BPF), were introduced to replace BPA as a healthier option. However, scientific research has confirmed their hormonal activity, thus continuing the same health issues [26,27].

Phthalic acid esters (PAEs), commonly known as phthalates, were used as polyvinyl chloride (PVC) additives; they are mainly used in the plastics industry (e.g., hair products, pharmaceuticals, and medical devices) as plasticizers and to provide durability and strength to materials [28].

Metal additives have many functions in plastics, such as biocides, antimicrobials, lubricants, and flame retardants, but are mainly used as inert fillers, pigments, dyes, and stabilizers. [29]. It has been reported that metals and metal complexes, although encapsulated in a polymer matrix, are not chemically bound to polymer molecules [30]. Metal-based additives used to colour plastics can potentially have an impact on the environment once the plastic is released into the natural environment. Lead is one of the most commonly detected metals in PVC products and may have a greater environmental impact. Munier and Bendell [31] report that plastics likely accumulate lead and copper from the environment, while zinc and cadmium come mainly from the production of plastics. Wang et al. [32] highlighted that most of the metals associated with microplastics are derived from their inherent load rather than being sorbed from the environment. A survey revealed that Pb additives inserted into microplastics, especially PVC, may have a greater environmental impact than adsorbed Pb. Moreover, a study has found that Pb additives in microplastics, particularly PVC, may have a greater environmental impact than adsorbed Pb [33,34]. Chromium is another metal mainly used for polymers such as PVC, polyethylene, and polypropylene. Also, the inclusion of Ti in plastic products acts as indicator of $TiO_2$, which is used both as white pigment and UV stabilizer [35].

Flame retardants (FRs) are inorganic and/or organic substances incorporated into raw polymers during the manufacturing process to prevent the flammability of the plastics. FRs are present not only on the surface of plastics and MPs but also inside them when added as additives during the manufacturing process, due to their highly lipophilic nature [36]. Considering the high lipophilicity of FRs, their rapid bioaccumulation is easily understood. The polybrominated diphenyl ethers (PBDEs) are FRs detected in various matrices, including human milk, article glaciers, household dust, and sludge derived from water treatment plants [36].

## 4. Sources and Transport of MPs in Marine Environment

MPs pollution in the ocean is one of the most serious environmental risks for a wide range of marine organisms across the planet.

Approximately 75% of marine waste is characterised by microplastics, of which approximately 80–90% originate from land-based sources, while only 10–20% originate from marine sources [37].

Marine litter results from unregulated disposal of waste in rivers, lakes, and channels that then are transferred to ocean, freshwater, brackish, or estuarine habitats. Microplastics (MPs) enter into the marine environments in several ways: primarily from surface runoff and wastewater (treated and untreated) but also from sewer overflows, industrial discharges, degraded plastic waste, and atmospheric deposition [38] (Figure 4).

The land-based supply sources consist of a myriad of items: bottles, plastic bags, building supplies, personal hygiene items, and apparel and synthetic fibres. Indeed, they can be released by using personal care products containing microbeads and through washing textiles, which shed microfibres. Every year, one million tonnes of synthetic fibres from the washing of clothes containing synthetic materials, such as acrylics, nylon, and polyesters, end up in wastewater streams, 50% of which is discharged into the environment. Previous studies reported that during the washing of a single garment, from 1900 to 1,000,000 fibres can be released, in particular over 6,000,000 fibres when washing polyester fabrics and 700,000 fibres from acrylic fabrics [39,40].

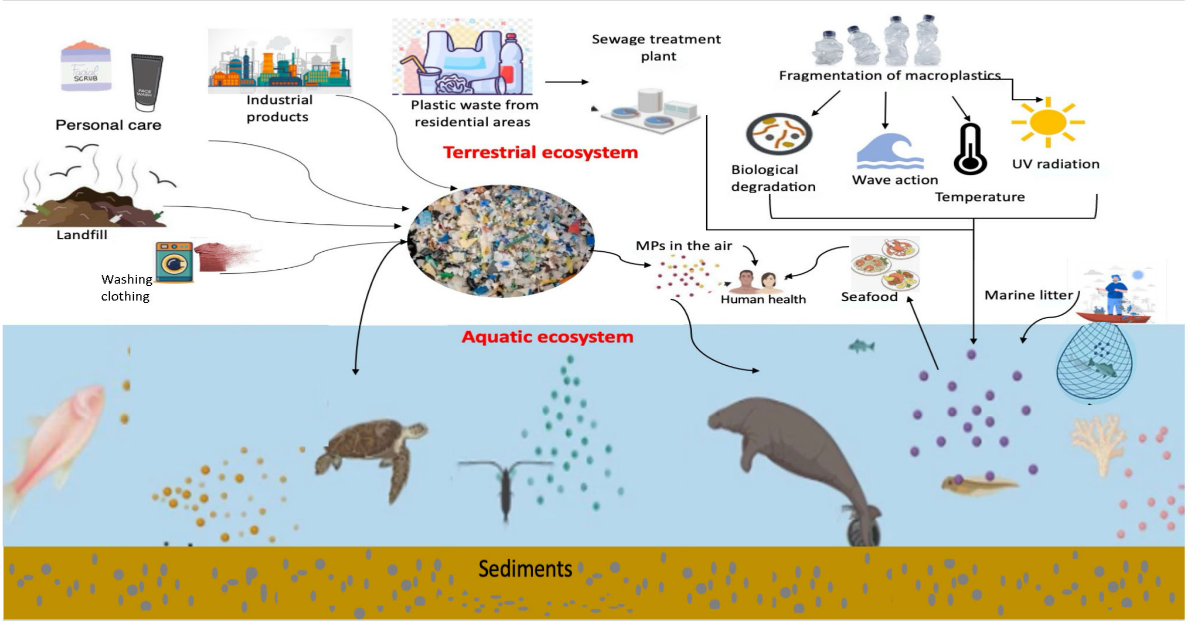


**Figure 4.** Microplastic sources and diffusion in marine environments.

Tyre dust is the largest source of MPs, followed by particle shedding from polymer-based paint and textiles that contribute significantly to the release of MPs into the environment. For the degradation of tyres, Sweden lost, from tyres, an emission of 10,000 tonnes annually, or just over 1 kg per capita, and Germany generates about 110,00 tonnes of particles, about 1.4 kg/capita/year. Paints used for road markings and house exteriors account for 10% of the microplastics released into the environment [41,42].

MPs found in air and urban dust can be the result of human activities (industrial, agricultural, or domestic). One more land-based source of these particles is plastic incinerators, which produce bottom and air ash that contains MPs. The small size of MPs allows them to remain suspended and be transported long distances from urban areas or inland regions to coastal areas. When the wind slows down and the air is dry, MPs can be deposited from the atmosphere into the sea surface. Once deposited on the sea surface, MPs can enter marine ecosystems, where they accumulate and represent a risk to marine life through ingestion and contamination of the food chain [43].

The marine sources contributing to the release of MPs are mainly represented by beach tourism, marine vessels, offshore industry, beach tourism, commercial fishing (abandoned, lost, or otherwise discarded fishing gear) and the transport of microplastic waste, often dumped by military and naval vessels [44].

One of the main pathways through which microplastics enter the aquatic environment is via wastewater treatment plants (WWTPs) [45]. In WWTPs, the stirring, mixing, and pumping of wastewater is another potential source of microplastics (MPs).

MPs in the sewage system are difficult to remove before the water is recycled or discharged into the marine environment.

It is estimated that MPs released to the environment after wastewater treatment are higher than the original levels. Studies showed that sludge produced from skimming units comprise large amounts of MPs, around 4000 to 7000 per kg of wastewater, which are 5 to 10 times greater than biosolids and grits. Lares et al. [46] stated that MPs were approximately 5 times higher in digested sludge than in activated sludge. Talvitie et al. [47] calculated that 20% of the MPs in the sewage sludge were returned to the wastewater flow through the reject water, while the remaining 80% ended up in the dry sludge for disposal.

## 5. Effects of Microplastics on Marine Organisms

### *5.1. MPs Uptake by Marine Organisms*

MPs pollution in the oceans is one of the environmental threats to many marine organisms. Recent studies have shown that plastic fragments, which persist in the environment, can be ingested and bioaccumulated by marine organisms [48]. Therefore, many taxa of the marine biota, including plankton, invertebrates, fish, sea turtles, and marine mammals, can be harmed by MPs directly or indirectly [49–53].

Once ingested and bioaccumulated by marine organisms, these particles can biomagnify along the food chain from primary producers to top predators [48], causing adverse biological and physical effects on marine life [54].

A variety of factors, such as habitat, geographical location, environmental position within the habitat (epifaunal, infaunal, etc.), feeding mode, size, lifespan, level of environmental contamination, or distance from the source(s) of plastic pollution, are likely to influence the extent and rate of uptake of microplastics by marine organisms [55].

Among them, the feeding mode of marine organisms plays a key role in the ingestion of MPs in their bodies. MPs can be confused with natural food by a wide range of marine organisms (e.g., crustaceans, molluscs, cnidarians, echinoderms, fish, and mammals), especially if it overlaps with their prey size range [56–58].

Filter-feeders, such as sponges, tunicates, and bivalves, actively feed on particles suspended in the water column, including MPs. They use cilia to create currents that transport particles to specialised feeding structures, so MPs enter these currents and are consumed. Abd-Elkader et al. [59] reported that MP concentrations (item/g) in the tissues of filter-feeding bivalve molluscs were higher than those of benthic gastropods or herbivorous echinoids along the Egyptian Red Sea coast. Walkinshaw et al. [60] found MPs in filter-feeding bivalve molluscs *Mytilus* spp. and cupped oysters *Crassostrea* spp.

The uptake rates of conventional plastic particles and bioplastic material appear to be very similar; Anderson and Shenkar [61] reported no significant differences in the absorption rates of MPs from PET and PLA in the tunicate *Microcosmus esasperatus*.

The presence of MPs in the guts, gills, and other tissues of aquatic organisms, including some commercially important shellfish, crustaceans, and fish, has been well documented, for example, in *Mytilus edulis* and *Mytilus galloprovincialis* in European countries [62].

Alfaro-Núñez et al. [63], in a study conducted in the equatorial tropical Pacific, reported the presence of microplastic fragments in 69% of the marine specimens analysed that were intended for human consumption, including fish, cephalopod molluscs, and crustaceans.

MPs can settle and be consumed by benthic deposit feeders or by detritivores such as annelids [55,64]. Deposit-feeders, which move along the surface or burrow into soft sediments, ingest sediments and assimilate the non-living and living organic matter, thereby contributing to nutrient cycling. These species play an important role in moving and distributing microplastics in aquatic ecosystems, particularly in relation to microplastic pollution. *Hediste diversicolor* is omnivorous with several distinct feeding modes, including scavenging, carnivory, filter feeding of suspended particulate matter in the water column, and deposit feeding from organic matter and detritus in and around the surface layers of sediment. *H. diversicolor* exposed to polyamide in the form of both microfragments in sediment and microfibers in water showed that filter-feeding worms uptake more fibres than worms that fed on microfragments, demonstrating that both feeding mode and particle characteristics significantly influence microplastic uptake by *H. diversicolor* [55].

Omnivorous fish consume more MPs than single herbivorous fish because of their broad feeding range [65]. Meanwhile, carnivorous fish can exchange MPs floating in the water column for food more easily than herbivorous and omnivorous fish [66].

Particles larger than 150 μm usually are not absorbed by tissues and cause only local inflammation. Smaller particles, instead, can induce systemic exposure and migrate to vital organs and are more available to animals at the base of the food chain [67].

### *5.2. Toxic Effect of Microplastics on Marine Organisms*

Because of their ubiquitous nature and small size, MPs can be uptaken by a wide range of marine organisms. The ingestion of microplastics is almost always accidental, as the particles are often mistaken for food [68]. Microplastic ingestion by marine organisms can cause mechanical effects, such as abrasion of feeding structures, polymer adhesion to external surfaces impeding mobility, and digestive tract obstruction, and moreover, chemical effects, such as inflammation, liver stress, and reduced growth [49].

Plastic polymers can leach their chemical additives in the marine environment and can be vectors of toxic compounds, such as organic contaminants, metals, and infection, due to their ability to absorb and accumulate pollutants from the surrounding water or release them [69]. Therefore, MPs in the marine environment can be considered as a complex mixture, since they can contain chemical additives, organic material, and living substances that can interact with the biotic and abiotic components and make microplastic more toxic in nature.

Several studies have investigated the effects of microplastic uptake and accumulation on marine organisms. Table S1 provides a list on a wide range of marine organisms, from small invertebrates to vertebrates, that are sensitive to microplastics, with lethal or sublethal effects [70–146].

#### 5.2.1. Phytoplankton

Phytoplankton is the basis of marine food chains, providing both energy and food for higher trophic levels, and has critical roles in ecosystem functions, such as carbon cycling.

The adverse effects of MPs on phytoplankton are well described and include altered gene expression, inhibition of cell growth, reduced photosynthetic capacity, reduced chlorophyll content, formation of heteroaggregates, inhibition of biomass productivity, and reduced environmental interactions due to surface adsorption [70–75].

Huang et al. [74] observed that the growth of the red alga *Porphyridium purpureum* was significantly inhibited at concentrations of PS-MPs up to 50 and 100 mg/L, together with a markedly reduced Fv/Fm value and increased levels of superoxide dismutase (SOD), catalase (CAT) enzymes, phycoerythrin (PE), and extracellular polysaccharide (EPS).

In diatoms, a low photosynthetic efficiency was observed after 72 and 96 h of exposure to polystyrene microspheres (PS-MPs) at a concentration of 200 mg/L [72].

High concentrations and smallest particle sizes of PS particles determine a reduced photosynthetic activity and reduced growth in the marine diatom (*Thalassiosira pseudonana*) and marine flagellate (*Dunaliella tertiolecta*) [77] (Table S1). Moreover, MPs can form aggregates with some phytoplankton species; for example, *Rhodomonas salina* has tended to take up more microplastic aggregate [75].

#### 5.2.2. Zooplankton

Many zooplankton organisms feed primarily in surface waters, where MPs abundance is high, thus increasing the chances of encounter and ingestion. The ingestion of MPs can damage the delicate structures of zooplankton, affecting their ability to feed, reproduce, and fulfil their ecological role. Zooplankton plays a fundamental role in the transfer of energy from primary producers to higher trophic levels, as they contribute to nutrient cycling by consuming and recycling organic matter into high-density, sinking-rate faecal pellets. Therefore, their decline can have cascading effects throughout the marine food web [147].

The exposure of the marine copepod *Tigriopus japonicus* to 50 nm and 10 µm PS microbeads revealed that smaller MPs induced more reactive oxygen species (ROS), significantly changing antioxidant-related gene expression and antioxidant enzyme activities [104] (Table S1). The smallest PS micro-beds, 0.05 and 0.5 µm size, caused mortality in *T. japonicus* in acute exposure, while MPs of 6 µm PS did not affect survival [105] (Table S1).

PP MPs revealed toxic effects on the early life stage of *T. fulvus* [103], while PE-MPs ranging from 1 to 500 µm did not show toxicity for *Acartia clausii* [78] (Table S1).

Also, the growth and reproduction of copepods showed an size-dependent MP decrease after being exposed to MPs for a period of 16 days [105].

#### 5.2.3. Other Marine Invertebrates

Exposure of barnacle larvae (*Amphibalanus ampitrite*) and brine shrimp (*Artemia fransiscana*) to PS MPs (≥1 mg/L) induced alterations in swimming speed after 48 h. In addition, exposure to MPs revealed variable effects on enzyme activity, as an increase in CAT activity was mainly increased at the high dose (1 mg/L), whereas effects on cholinesterase (acetylcholinesterase and propionylcholinesterase) appeared more random, with no clear dose dependence [120] (Table S1).

*Paracentrotus lividus* is widely used marine model organism for the ecotoxicological response to environmental pollutants. Oliviero et al. [107] observed a decrease in larval length (*P. lividus*) when exposed to low concentrations (0.3 mg/L) of PVC-MPs and a block of larval development in sea urchin embryos exposed to the highest dose (30 mg/L). Moreover, an evident toxic effect due to leached PVC was observed, manifesting as developmental arrest, immediately after fertilization and morphological alterations in plutei [91]. PVC products with different colours showed different toxicity, probably due to a different content and/or combination of heavy metals present in colouring agents [107] (Table S1).

To compare the toxicity of MP leachates of commercialized biopolymers (PHB, PLA PLA/PHA) with the plastic petroleum-based (PVC), Uribe-Echeverría and Beiras [108] have demonstrated that the leachates of these bioplastic materials were innocuous for the larvae of *P. lividus*, with a slight toxicity for PHB, while PVC leachates were the most toxic for *P. lividus*, likely due to the added plasticisers (Table S1).

A study on the acute toxic effects of MPs (≤38 µm) of PS and PP on *Gammarus aequicauda, Cymodoce truncata,* and *Idothea baltica* showed toxic effects on all crustacean species tested, with LC50 values ranging from 2.73 mg/L to 80 mg/PP/L. PS-MP resulted in an acute lethal effect (LC50 = 20.90 mg/L) only on *G. aequicauda* [103].

Sea cucumbers have a high susceptibility to bioaccumulate marine pollutants, making holothurians effective bioindicators of microplastic pollution. Studies have shown that MP toxicity in marine organisms occurs via physical or biological effects [117–119] (Table S1).

Recent evidence has indicated that effects of PE and PP-MPs are bioaccumulated in the gastrointestinal tract and coelomic fluid of sea cucumber (*Holothuria tubulosa*) specimens, determining oxidative stress (i.e., catalase, glutathione S transferase, malondialdehyde, and DNA damage) [118] (Table S1).

The polychaete lugworm, *Arenicola marina marina*, is a crucial organism in the benthic ecosystem since it is responsible for reworking the sediments in which it lives. It is responsible for the distribution of inorganic nitrogen, such as ammonium ($NH_4^-$), nitrate ($NO_3$), and nitrite ($NO_2$), between the water column and sediments, making it available to other benthic organisms [51]. Green et al. [51] observed that in the presence of high doses of MPs, *A. marina* reduced its bioturbative activity, thereby reducing primary productivity, altering ammonium flux, and changing the benthic habitat structure.

Mussels, as sessile filter-feeders, are excellent marine animals to study the intake and accumulation of MPs, being considered as bioindicators of coastal pollution. Exposure to

MPs may have biological impacts on mussels, including negative effects on the immune system [80] and genotoxic effects [50,80,81] (Table S1).

There is strong evidence of a marked ability of contaminated MPs to transfer chemical contaminants to exposed mussels (*Mytilus galloprovincialis*), with indications of potential transfer and bioaccumulation of chemical in mussel tissues.

Both virgin and contaminated PE-MPs and PS-MPs induced several effects at the transcriptional and cellular level, highlighting the potential risk for the health status of organisms, especially under conditions of long-term chronic exposure [50].

The effects of HDPE-MPs and of biodegradable MPs PLA on flat oyster *Ostrea edulis* showed no alterations in filtration and growth rates, but respiration rates were elevated in response to the high dose of PLA microplastics, suggesting that biodegradable MPs in the *O. edulis* induced stress [92] (Table S1).

#### 5.2.4. Fish

Fish play a vital role in the marine ecosystem as both predators and prey. They contribute to the overall health and stability of the ecosystem by helping to maintain the balance of the food chain. They show different levels of susceptibility to MPs due to the diversity of the habitats in which they live as well as the characteristics of the MPs. The presence of plastic debris in the stomachs of large pelagic fish in the Mediterranean has been demonstrated [148]. Lusher et al. [149] found microplastics in 36.5% of the gastrointestinal tracts of pelagic and demersal fish.

The ingestion of MPs can lead to different adverse effects on fish, including physical damage to vital organs. In *Dicentrarchus labrax*, PVC and PE-MPs induce histopathological lesions in liver and intestine and alterations in the immunity system [138]. PE-MPs have been reported to significantly reduce acetylcholinesterase (AChE) activity in juveniles of the common goby *Pomatoschistus microps* together with oxidative damage [140,141].

Chronic exposure of marine medaka (*Oryzias melastigma*) to PE and PLA MPs at the same concentration (200 µg/L) had no significant effect on body length and weight of marine medaka larvae. However, pathological damage to intestinal tissues was observed, even if there were no significant changes in the composition of the intestinal microbiota [142,143].

Metabolic parameters in the serum of *Sparus aurata* fed 100 or 500 mg/kg of PVC microplastics for 30 days showed that the dietary intake has a negative impact on fish physiology due to the chronic stress produced [139] (Table S1).

MPs can be ingested by fish and can accumulate in the digestive tract, leading to a feeling of fullness and consequently to a decrease in available energy [150]. They can also interfere with the natural reproductive behaviour of fish, resulting in reduced courtship behaviour, impaired mate choice, or reduced spawning activity [150].

### *5.3. Occurrence of Microplastics in Commercial Marine Species*

Seafood plays an important role in the human diet due to its high nutritional value. However, several studies showed an MP contamination of commercial seafood.

Human consumption of seafood is a significant source of human exposure through which MPs enter the human body [151].

Contaminated seafood can pose a risk to human health, especially when small fish and shellfish are eaten whole [152]. Smaller commercial seafoods, such as bivalvia, shrimps, and decapod crustaceans, are more likely to be impacted by MPs compared to larger fish because microplastics fall in a similar size range to their prey.

In Table S2 has been reported a summary of the MP presence in numerous marine species of commercial interest [62,153–206].

The ingestion of MPs has been observed in many species of fish intended for human consumption from the Pacific, Atlantic, and Indian Oceans, and the Mediterranean Sea.

Studies have revealed that the number of total MPs in two species of mussel commonly consumed as food by humans (*Mytilus edulis* and *M. galloprovincialis*) ranged from 0.4 to 7.7 MPs/individual and from 0.04 to 11.4 MPs/g ww [62,156,157,159] (Table S2).

In samples of oysters (*Crassostrea gigas*) reared in Salish Sea, USA, a content between 0.69 and 3 MPs/individual were found, while on the Atlantic Ocean coast, Nantes-France, were counted 2.10 $\pm$ 1.71 MPs/individual [160,164] (Table S2).

Curren et al. [171] reported the presence of MPs in three commercial shrimp species purchased from supermarkets in Singapore, the Pacific white shrimp *Litopenaeus vannamei*, the Argentine red shrimp *Pleoticus muelleri*, and the Indian white shrimp *Fenneropenaeus indicus*. The results showed that the abundance of MPs ranged from 13.4 to 7050 g/ww, with *Pleoticus muelleri* being the species with the highest number of items.

*Fenneropenaeus indicus*, from the coastal waters of Cochin, India, showed an average of 0.39 $\pm$ 0.6 MPs/shrimp (0.04 $\pm$ 0.07 microplastics/g ww). The shrimp contamination was significantly higher during the monsoon season (July–August) [168].

In another study on Indo-Pacific shrimp (*Penaeus semisulcatus*) sampled in the Persian Gulf, the authors observed an average of 0.36 MPs/individual [172].

MPs have also been found in fish of great commercial importance, such as sardines (*Sardina* pilchardus) and anchovies (*Engraulis encrasicolus*), which are often consumed entirely, posing a greater threat than gutted fish. However, little is known about MPs levels in small fish. The ingestion of MPs has been observed in many species of fish intended for human consumption, for example, in seasonal migratory fish (e.g., *Sparus aurata* and *Dicentrarchus labrax*) and sedentary fish (*Solea solea*), mediterranean horse mackerel (*Trachrus mediterraneus*), common pandora (*Pagellus erythrinus*), European hake (*Merluccius merluccius*), and Flathead grey mullet (*Mugil cephalus*) (Table S2).

The ability of MPs to bioaccumulate in marine organisms and translocate from the gastrointestinal tract to other tissues of aquatic organisms has raised concerns about the safety of seafood, especially species for human consumption [207].

## 6. Impact of Plastic on Human Health

The World Health Organization found that human exposure to MP occurs predominately through inhalation or by the diet [208].

Inhalation is an important route by which plastic particles can enter the human body. The air is one of the most important ways people are exposed to pollutants, like MPs, which may be inhaled during breathing. The airborne spread of MPs varies as they can be transported by wind or atmospheric deposition, and they can originate from abrasion of plastic materials, landfills, sewage sludge and waste incineration, synthetic textiles, construction materials, or road-wear particles [209].

The ubiquitous presence of MPs in the environment raises serious concerns about their exposure and effects on human health, as atmospheric MPs can be inhaled by humans and deposited in the alveoli [210]. They can also be carrier of chemical additives and vectors of pathogens and parasite [211]. Some studies demonstrate that persistent fibre inhalation may cause local biological responses that result in inflammation, contributing to cancer development [212]. Inhaled particles can cause immunotoxicity, cytotoxicity, and detrimental effects on the respiratory system, such as alveolitis and chronic bronchitis [213].

Ingestion of foods contaminated with MPs, including seafood [155], commercial processed fish [214], sea salt [215], honey and sugar [216], beer [217], and beverages, is considered to be a relevant route of exposure.

In a study assessing the amount of MPs in different foods, Cox et al. [151] estimated that the average ingestion of MPs per person is 39,000–52,000 per year.

These estimates can rise to about 74,000 particles considering also the inhaled MPs; furthermore, adding also the MPs contained in drinking water 4000 or those contained in water bottled in plastic, the number increases by 9000 particles. These values are likely to be underestimated due to methodological and data limitations [151].

MPs can enter the gastrointestinal system through contaminated food or by mucociliary clearance after inhalation. Absorption of MPs in the gastrointestinal tract can occur by several mechanisms and is closely related to particle size. In the intestine, small particles could be adsorbed by specialized M-cells, causing intestinal inflammation with increased cytokines and chemokines. In addition, intestinal barrier cells alter their permeability and microecology in response to the presence of MPs, affecting energy metabolism and leading to adverse health effects [218].

MPs over 0.7 μm have been reported in human blood at 1.6 μg/mL, confirming the potential for translocation from the environment into the systemic circulation [219].

Strong evidence that MPs have been ingested through the food chain and exposed to the stomach is their presence in human faeces [220]. In human faeces, up to 138.9 MPs/g in the form of fragments, films, and fibres were found in more than 95.8% of samples [220,221]. Higher amounts of MPs were found in the faeces of patients with inflammatory bowel disease (41.8 items/g) compared to healthy people (28 items/g) [222].

Dermal exposure can occur when humans interact with MP-contaminated water or soil or through contact, including the use of hand cleansers, facial/body scrubs, face masks, and toothpaste, which may result in local toxicity and possible absorption [223]. Dermal uptake has received much less attention than ingestion and inhalation. This is because the dermal barrier prevents the absorption of particles larger than 0.1 μm [224].

Due to the limited size of MPs that penetrate the skin, dermal absorption has been mainly associated with the uptake of released monomers or to phthalates and bisphenols used as plasticizers [225].

MPs have a negative impact on skin health, with previous research demonstrating their ability to cause skin irritation, inflammation, and disruption of natural skin functions [226].

## 7. Conclusions

The reviewed studies confirmed the negative impact of MPs on marine organisms and human health. The physical and chemical properties of microplastics have a significant impact on marine organisms' toxicity. Understanding the relationship between microplastic properties and mechanisms of uptake and toxicity can help to assess the potential risks of MPs to ecosystems and human health and provide a scientific basis for formulating relevant environmental and health management policies.

Based on the "*One Health*" principle, there is an urgent need to address this global environmental problem. Although human studies are a priority, there is an urgent need to fill some knowledge gaps. There is a lack of standardized methods for defining and detecting MPs, which can lead to the underestimation of the precautionary exposure level. Most of the research is conducted in the laboratory; therefore, there is a need for comparative laboratory–field experiments to assess and improve the understanding of the real effects of MPs. There is a need for estimating daily exposure in human populations through a robust risk analysis. Overcoming these challenges is essential to advancing research in this area.

**Supplementary Materials:** The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/w17070916/s1: Table S1: Summary of reviewed studies on microplastic toxicity to marine organisms. Table S2: MPs Occurrences in commercial seafood.

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