An overview of the sources, impacts, and management techniques of microplastics in the marine environment

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ABSTRACT

The presence of microplastics in the sea is a significant environmental concern due to their abundance, persistence, and portability. They have the potential for widespread distribution and can cause geophysical and biological impacts. They are persistent pollutants and are widely distributed in all ecosystems, from the atmosphere to the soil, and from groundwater to oceans. Examples of these compounds have been identified in sediments and even in the deep sea. So far, studies on the effects of microplastics on the marine ecosystem have primarily focused on various plankton samples, sand and mud sediments, the ingestion of vertebrates and invertebrates, and the interactions with chemical pollutants. According to studies conducted so far, all groups of marine organisms are at serious risk of interacting with microplastics. Considering this scientific fact, a thorough evaluation of these emerging pollutants is strongly needed. The purpose of this study is to provide valuable information on microplastics, including their sources, distribution, and the effects of pollution on marine organisms. Additionally, this study aims to address the lack of advanced sustainable solutions to effectively manage this hazardous environmental pollutant.

1. Introduction

Plastic is a synthetic organic polymer with high molecular weight that is made from the by-products of fossil fuels, coal, oil and natural gas. The desirable characteristics of plastics are: light weight, low cost, durability, flexibility, resistance to electricity and water. These distinctive features have surprisingly increased in demand and of course its generation. Therefore, the production of plastic waste has increased every year [1-3]. Therefore, these special products, which were once introduced as "the great invention of the 20th", have caused severe environmental problems [4]. In the 1950s, global plastic production was 2 million tons, while this has increased to 348 million tons in 2017 and 359 million tons in 2018. China is the largest producer of plastic products in the world, followed by Europe and North America [5]. In 2010, about 12.7-4.8 million tons entered the ocean [6], and it is predicted that by 2025, about 250 million tons of plastic waste will enter the ocean [4].

While scientific communities are dealing with a huge amount of mismanaged plastics, the arrival of microplastics has created a new problem for the world [7]. Therefore, the existence of microplastics in different environments such as rivers, underground waters, oceans, soil, living organisms, atmosphere, tap water and even arctic snow has been studied by many scientists [6, 8-21]. A number of researchers have stated that microplastics are plastic particles with sizes of 0.1 µm to 5 mm [22-28], they also indicate that nanoplastics are plastic particles smaller than 0.1 µm [28-30], but Crawford and Quinn [31] have presented another category of plastic particles in their books called "Microplastic pollutants", which is shown in Table 1. Since different classifications have been reported for plastic particles and there is still no uniform standard for their definitions and reorganization, it seems necessary to provide an official classification of plastic particles in the world.

Since microplastics end up in the aquatic environment, due to their capacity to absorb and accumulate different

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types of pollutants, they may become the center of pollutants ranging from toxic to persistent organic pollutants, such as pesticides, POPs, and flame retardants and PCBs [32, 33].

Due to the ubiquitous nature of microplastics, humans are ultimately exposed to these particles through drinking water containing microplastics, eating food and living organisms containing microplastics, inhaling air contaminated with microplastics, and skin contact with microplastics found in personal care products, dust, and microplastics. Placed. Therefore, despite little information about the impact of microplastics on human health, they should be considered as emerging pollutants in the world [34].

Microplastics are potentially ingested by aquatic organisms, including micro and nanoplankton species [35]. Transport of toxins at trophic levels through this mechanism is very common. Since aquatic species form the basis of the aquatic food web, any threat to them can have serious and widespread effects in the world's oceans [36]. The potential fate and pathways of microplastics through marine vertebrate and invertebrate groups are shown in Fig 1. Organisms at every level of the marine food web eat microplastics, but those living in industrial areas are exposed to higher amounts and may be more contaminated. These compounds accumulate in the bodies of living beings and, by releasing toxic substances, they cause reproductive disorders [37]. Therefore, there is an urgent need to quantify these potential consequences and assess the future impact of increasing microplastic levels in sea water.

Table 1. Classification of plastic particles [31]

Category	Abbreviation	Size	Size definition
Macroplastic	MAP	≥25mm	Plastic particles equal to or larger than in the size of its longest dimension
Mesoplastic	MEP	<25 mm–5mm	Plastic particles with a size ranging from 25mm-5mm along its largest dimension
Plasticle	PLT	<5 mm	Plastic particles smaller than 5mm in size along its longest dimension
Microplastic	MP	<5 mm–1mm	Plastic particles with a size ranging from 5mm-1mm along its longest dimension
Mini-microplastic	MMP	<1 mm–1μm	Plastic particles with a size ranging from 1 mm–1μm along its longest dimension
Nanoplastic	NP	<1μm	Plastic particles smaller than 1μm in size along its longest dimension

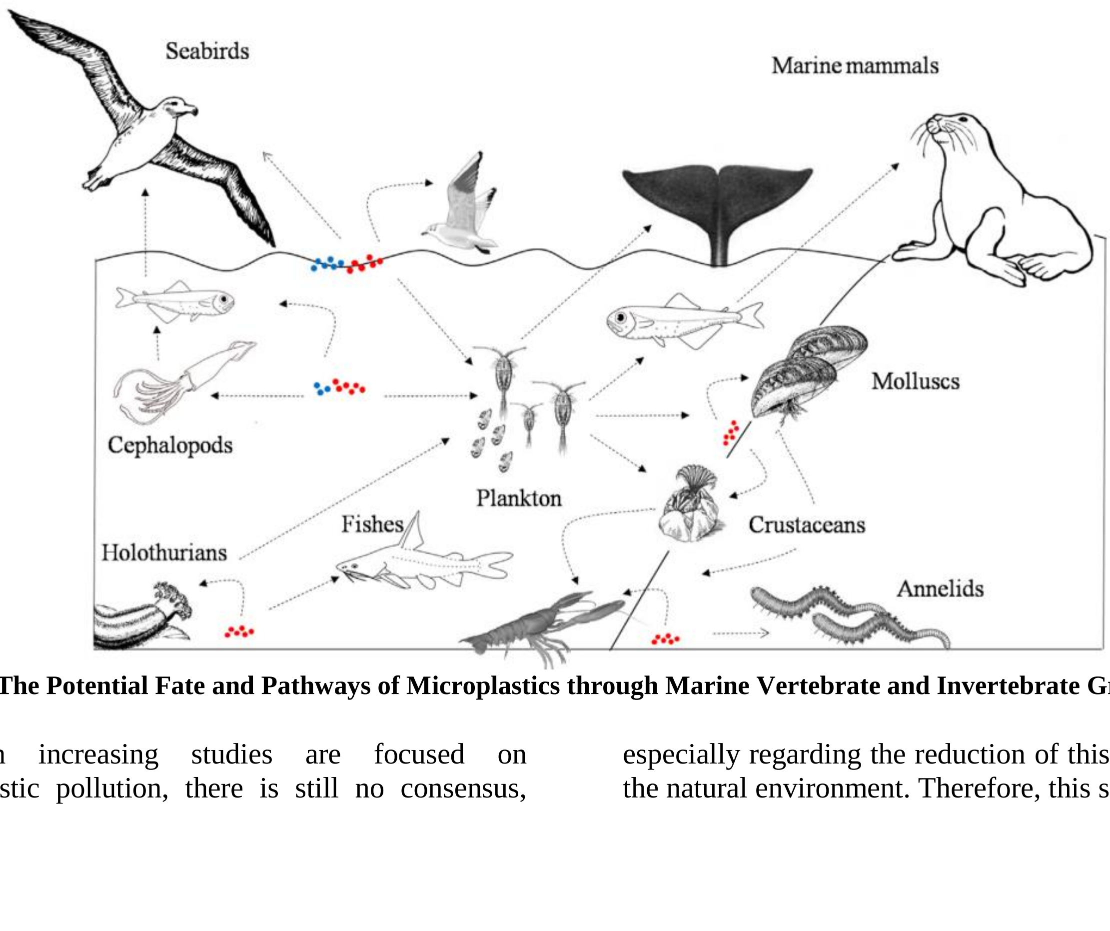

Fig 1. The Potential Fate and Pathways of Microplastics through Marine Vertebrate and Invertebrate Groups [36]

Although increasing studies are focused on microplastic pollution, there is still no consensus, especially regarding the reduction of this pollutant in the natural environment. Therefore, this study aims to

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review articles, books, and previous information about microplastics in recent years and address the issues of sources, distribution, fate, impacts, sampling, and detection of microplastics with a focus on integrating strategies to reduce microplastics from the environment, especially in aquatic environments.

2. Sources, fate, distribution, and effects of microplastics

2.1. Resources and destiny

Microplastics are found in colors, shapes and types of polymers in the environment [38], which is a proof of the existence of different sources of microplastics. Sources of microplastics are defined as the locations, products or practices where microplastics are produced [39]. Understanding the different sources of microplastics is very important because it can help reduce the social, environmental and economic impacts of microplastics [40]. The classification of potential sources of microplastics is different in different studies [40]. Different studies have classified different categories for different types of microplastic sources [40]. Many researchers have divided microplastics into two categories based on the processes by which they are made: primary and secondary microplastics [41]. Primary microplastics are resin pellets and microbeads that are used to make other plastic products such as cosmetics and personal care products such as toothpaste, body washes, facial cleansers, hair gel, sunscreen, etc. [41-44]. In cosmetics, a significant amount of plastic microbeads are usually spherical or irregular and are used for exfoliation or cleaning [45]. The concentration of plastic particles in facial scrubs can reach 50,391 particles per gram [40]. It is estimated that a single face wash using one of these products can release about 94,500 microbes into the drainage system [45]. In contrast, secondary microplastics result from the degradation of larger plastics in the environment [46]. As shown in Figure 2, several processes are involved in the degradation of plastic particles that produce secondary microplastics, such as road markings, landfills, garbage, laundry, etc. Therefore, secondary microplastics are the dominant type of microplastics in the environment. It is estimated that one wash of clothes made of synthetic textiles can release more than 1900 microplastic fibers into the wastewater. Some researchers have divided the sources of microplastics into two categories, land-based microplastics and sea-based microplastics, based on the location of the microplastics. Some scientists have divided the sources of microplastics into point sources or diffuse sources based on the type of entry into the environment. Although there is a rudimentary understanding of the characteristics of that classification system, researchers have defined point sources as sources with a specific point of discharge and diffuse sources as sources without a specific point of discharge [47]. While others divided them based on the shape and texture of the surface, microplastics with a smooth texture and symmetrical shape are called primary microplastics and asymmetric shapes with an uneven surface are called secondary microplastics [40].

Inspired by Figure 2, Table 2 lists the sources of microplastics, the route of entry, the type of microplastic, the type of release and their final destination.

As shown in Figure 1, microplastics from the washing of synthetic textile clothing, personal care products, and cosmetics enter municipal wastewater and then sewage treatment plants. A significant part of the microplastics in the wastewater is removed through the processes in the wastewater treatment plant and enters the sewage sludge. Therefore, sludge, as a rich source of microplastics, can be a huge source of microplastics entering the environment if it is used as fertilizer in agriculture, animal feed or buried in landfills. However, since the efficiency of wastewater treatment plants is generally not 100%, some microplastics remain in the effluent of the treatment plants [45]. That small percentage of microplastics remaining in wastewater is the source of significant microplastics entering the environment. Gong and Xie [2] show that although the removal rate of the wastewater treatment system is 98%, 65 million microplastics enter the water through wastewater treatment plants every day.

It is inferred from Table 2 and Figure 1 that the construction industry can make a large contribution to the production of plastic materials in the environment by using materials such as plastic bags, plastic pipes, glue, concrete [48, 49], insulating materials [50], etc. During or after manufacturing, plastic materials may be released into the environment due to carelessness or improper storage [51]. Plastic materials can enter the atmosphere through the wind and eventually reach the oceans, soil or poles.

Plastic mulch has been applied to 20 or more million hectares of agricultural land worldwide to significantly improve crop yield and water use efficiency [52]. Plastic mulching is a potential source of macroplastics and microplastics in agricultural fields. Due to its intense use and improper disposal [53]. Therefore, plastic layers left on agricultural land can turn the soil into a reservoir of microplastics, destroy the soil structure, and change the distribution and natural transport of water [52]. It is possible that these plastic particles will eventually be transferred to the underground water.

Landfill is a widely used strategy to get rid of municipal solid waste (MSW) worldwide. Due to the lack of proper classification of waste and insufficient

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plastic recycling infrastructure, plastic materials constitute a significant part of MSW Microplastics in cosmetics, personal care products or synthetic textiles may end up in landfills via sewage sludge. Other plastic particles buried in landfills may also be converted to microplastics under harsh conditions [54]. Therefore, landfills are theoretically primary sources and potential sinks of microplastics in the environment. These microplastics may enter the surrounding atmosphere through airborne pathways and can also enter rivers, groundwater, and even the ocean through leachate [54, 55] and ultimately reach host ecosystems. Therefore, the control and management of landfills as a source of microplastics is limited [56].

Many sports equipment such as stadium seats, nets, gym floors and artificial turf [57] are made of plastic. Therefore, since there are a significant number of these sports fields in various urban and rural areas around the world, sports fields can be considered as one of the important sources of microplastic production. These microplastics may eventually reach receiving environments.

Human dumping of plastic waste on land or sea is one of the ways that plastic enters the environment. These plastics are mainly: cigarette butts, water bottles, bottle caps and packaging materials [39, 57].

Table 2. Overview of sources, entry routes, type of sources, type of release and final destination of microplastics in the environment

sources	Entry paths	Type of MPs	Type of entry	Final destination
Personal care product & Cosmetics	Wastewater & sewage sludge	Primary MP & Land-based	Point-Diffuse	Human's body (direct), Soil/groundwater, ocean
Agriculture mulching	Wind & Soil	Secondary MP & Land-base	Diffuse	Human's body (Inhale the air), Poles, Soil/groundwater
Washing clouds	Wastewater & sewage sludge	Secondary MP & Land-based	Point-Diffuse	Soil/groundwater, ocean
Shipping, Fishing & Diving	Drifting	Secondary MP & Sea-based	Point-Diffuse	Human's body(direct), ocean
Road marking & Tiers Abrasion	Wind & Surface runoff	Secondary MP & Land-based	Diffuse	Human's body (Inhale the air), Soil/groundwater, ocean
Construction	Wind, Drifting & Surface runoff	Secondary MP & Land-base	Diffuse	Human's body (Inhale the air), Soil/groundwater, ocean
Sport grounds	Drifting & Surface runoff	Secondary MP & Land-base	Diffuse	Ocean
Littering	Drifting & Surface runoff	Secondary MP & Land-base	Diffuse	Soil/groundwater, ocean
Industrial plastic production	Drifting & Surface runoff	Primary MP & Land-base	Point-Diffuse	Ocean
Landfill	Drifting & Surface runoff	Secondary MP & Land-base	Diffuse	Soil/groundwater, ocean

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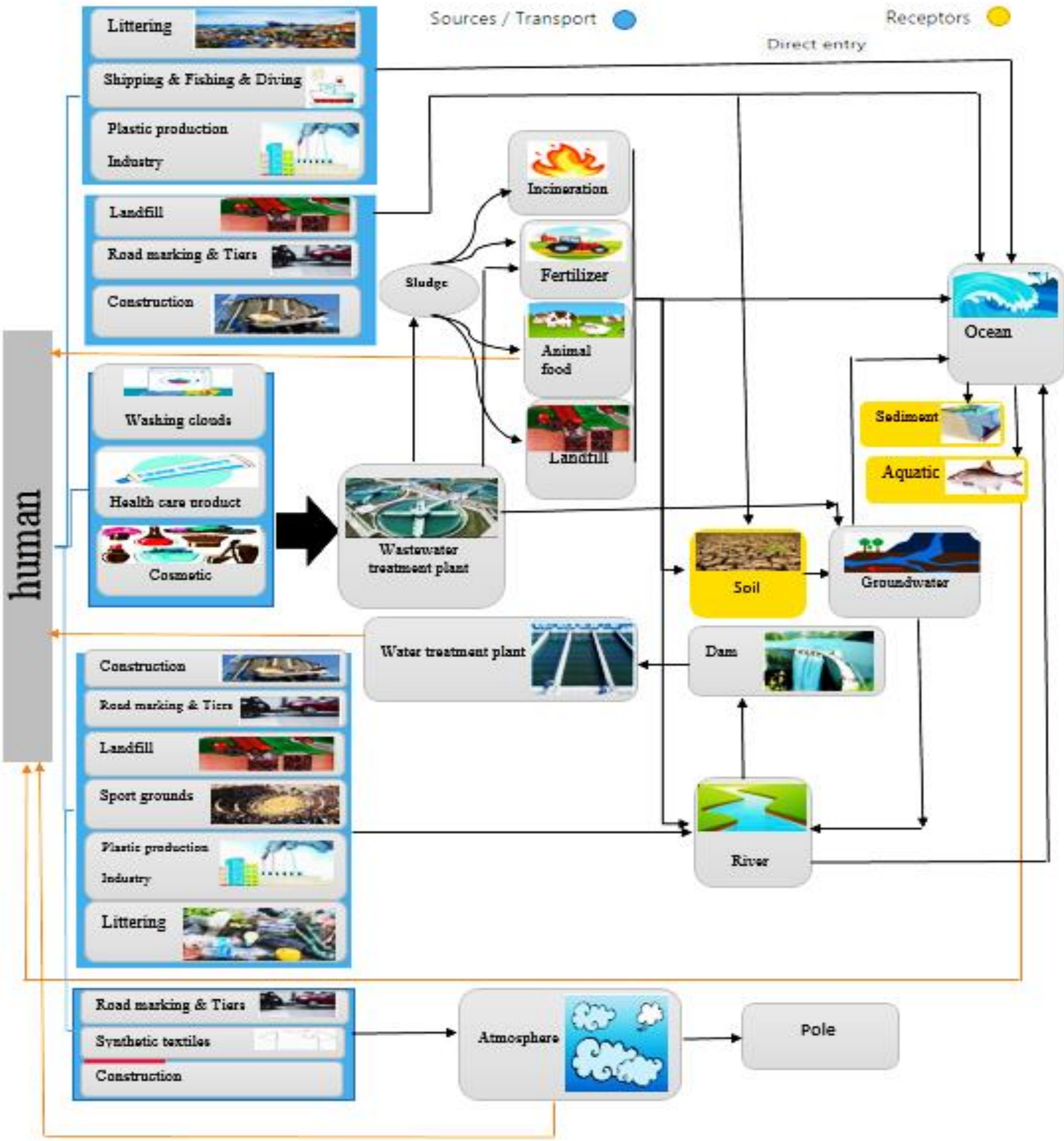

Fig 2. The Sources and fate of microplastics

Those plastic particles may become microplastics under the influence of mechanical fragmentation or chemical degradation [58]. Then, the (micro) plastics that arise from the waste, under the influence of factors such as wind, sea waves, ocean currents and their density, may eventually reach various places such as rivers, estuaries, sediments, distant islands, and ocean [59].

Tire and road wear particles (TRWP) are a significant proportion of microplastics in the environment [47, 60, 61]. TRWP is released either unintentionally as an attrition product from tire wear or intentionally as micronized “crumb rubber” on playgrounds as infill materials [62]. The amount of microplastic release from tires to the environment is related to local conditions [36] such as road roughness, temperature, etc. Therefore, the amount of microplastics released into the environment from TRWP varies in different countries. For example, it is estimated that the amount of microplastics from tire rubber in the United States is about 1,524,740 tons/year, while it can be 1,300,000 tons/year in Europe and 20,000 tons/year in Australia

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[63]. However, road markings are another important source of road dust-related microplastics released into the environment that should not be ignored [63]. These released microplastics may contribute to the emission of non-exhaust gases into the air. However, massive TRWP, coarser heterogeneous particles, are transported to road surfaces, soil, or eventually end up in the aquatic environment with storm water [61].

Diving, sailing, fishing can also be a source of microplastics. However, they share a small proportion of microplastics compared to other sources of microplastics. Because the international shipping regulations MARPOL Annex V, which was adopted in 1990, prohibits ships from directly disposing of waste in the ocean [39]. However, it is inevitable that primary microplastics enter the seas through sunscreens used by swimmers, ship paint corrosion, lost fishing gear, etc.

2.2. Microplastic distribution process

The distribution process of microplastics can be horizontal or vertical, which is presented separately below.

2.2.1. Horizontal distribution of microplastics

Horizontal transport of microplastics may occur due to hydrodynamic processes such as ocean currents, river currents, wind, etc. Finally, microplastics are transferred from their sources to different environments such as oceans, soils, sediments, poles [64, 65]. The distribution and abundance of microplastics in other parts of the world depends on the strength of environmental factors such as winds, stormwater, ocean gyres and human factors such as wastewater treatment technologies and sludge management [66]. Based on studies from 2007 to 2013 from 1571 sites worldwide, it is estimated that there are more than 5.25 trillion pieces of plastic on the surface of the world's oceans with a mass of at least 268,940 tons, of which 35,450 tons are microplastics [67].

2.2.2. Vertical distribution of microplastics

Several studies have investigated the vertical distribution of microplastics in the water column [64, 68-71]. Almost the main reason for the vertical transport of microplastics is the density of polymers. For example, polymers such as polystyrene [13], polystyrene acrylonitrile , pSA), acrylonitrile butadiene styrene (ABS), polyamide , pA) (nylon), polymethyl methacrylate (acrylic) , pMMA), polyvinyl chloride , pVC)), polylactic acid , pLA), polycarbonate , pC), polyethylene terephthalate , pET), polyoxymethylene , pOM), polyester , poly), cellulose acetate, which are denser than seawater, in the water column while low density polymers such as low density polyethylene (LDPE), polyethylene , pE), high density polyethylene (HDPE), polypropylene , pP) and expanded polystyrene [13] may be float in sea water.

3. The effect of microplastics on marine organisms

the most studies have addressed microplastic pollution in marine organisms by examining fish living in the pelagic zone. However, information is limited when species from different trophic levels or different environments are a concern. Although an increasing number of studies on invertebrates such as anemones have been conducted in recent years, the information obtained is still insufficient to properly address the relationship between microplastics and gastropod communities.

The presence of microplastics in the sea is of great concern due to their abundance, persistence and portability, with the potential for widespread distribution, subsequent geophysical and biological impacts. Worldwide, research on the ingestion of microplastics by biota has been mainly conducted on a wide range of marine species in different feeding forms [72]. Since it has been shown that microplastics limit food consumption, they cause physical damage and oxidative stress, reduce energy allocation in various aquatic organisms, and in some cases damage the digestive tract [73]. Changes in the feeding behavior of some types of crustaceans, such as pods that feed on algae, were also studied, but when these pods were fed from the natural collection of algae with the addition of polystyrene microbeads, they showed a significant decrease in herbivory, which caused a decrease Their growth rate will be [74]. Microplastics affect the physical structure of organisms. A variation in the life cycle of the sea urchin Paracentrotus lividus was shown to depict changes in the shape of planktotrophic larvae of the pelagic Plateus when microplastics are ingested [75].

Some chemicals caused by microplastics disrupt the activity of endocrine glands and are responsible for hormonal imbalance in organisms. In a study by Sussarellu et al. in the oyster [76], which is a major species with high ecological and economic value. When mature oysters were exposed to polystyrene microplastics about 2 micrometers in diameter at a critical point in their reproductive stage, the adults were ready to produce gametes. And after exposure, there was a change in feeding efficiency as well as food intake. Reproductive changes also showed that the quality of eggs and sperm swimming speed as well as their fertility decrease. These changes had an effect on the quality of offspring and further reduction of growth in larval progeny. Similar effects were observed in plankton pods when they were exposed to micropolystyrene for long periods of time, followed by reduced food consumption and thus reduced reproductive output [۷۳].

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However, corals found both in the deep sea and in the Antarctic region have not been affected by microplastics. Studies show that corals that eat microplastics have an obvious negative impact in terms of energy levels, growth and growth and pathogen frequency of reefs [77].

4. Solutions to deal with plastic particles

Due to the widespread presence of plastic particles in the environment, the consumption of plastic has led to the creation of a legislative body in many countries, which monitors and regulates the use and disposal of plastic due to the reduction of their presence in the environment. In this regard, there are two excellent reviews that are highly recommended for interested readers that cover the US and European situation from a plastics life cycle perspective. Both studies identified regulatory gaps and limitations and how to fix them to limit and prevent environmental exposure to microplastics and their risks. Both articles have also emphasized the urgent need for proper implementation and enforcement of the law as well as for improving plastic waste management practices, source control and cleanup. Also, strategies based on changing citizens' behavior, including recycling and consumption and demand for available plastics, should be prioritized in order to reach more ambitious goals for recycling and recovery.

In addition to the above measures, new treatment technologies have been used to overcome plastic pollution. These purification measures can be divided into biotechnology methods and non-biotechnologies. The second case includes advanced wastewater treatment technologies, as wastewater treatment plants can provide a solution to reduce the point source entry of microplastics into the environment. There are many studies that have investigated the ability of these technologies to destroy plastics. The efficiency of the membrane bioreactor process for removing microplastics (99.4%) has been much better than all conventional activated sludge-based processes (98.3%). Rapid gravity sand filters (RSF), dissolved air flotation (DAF) and membrane bioreactor (MBR) were used as complete treatment in Finland. Wastewater containing microplastics was treated with all three methods and all three showed a removal rate of microplastics greater than 95%. Biological active filter is also an important process to remove these particles.

The third solution to solve the problem of microplastics is to use more biodegradable materials. Bio-based polymers are obtained from renewable raw materials, such as starch, cellulose, lignin and bioethanol, most of which are biodegradable polylactitol and polyethylene. A big problem with biodegradable plastics is that they can biodegrade, but this process requires the right conditions and specific microorganisms. Some of their degradation products have already been detected in water.

The last one is based on bioengineered solutions. In fact, this is the use of microorganisms that are able to destroy plastics, such as different types of bacteria, fungi, or hydrolytic enzymes. Various efforts have been made to identify and isolate microorganisms that are able to use synthetic polymers. Yoshida et al showed how biodegradation of plastics by specific bacteria can be a suitable bioremediation strategy. The new species, Ideonella sakaiensis, breaks down plastic using two enzymes to hydrolyze PET and a primary reaction intermediate, ultimately creating essential blocks for growth. Enzymatic hydrolysis of PE has also been reported. In addition, Zalerion maritimum mushroom was tested for polyethylene degradation and it was shown that this natural mushroom may actively contribute to the biological degradation of microplastics, also this type of mushroom requires minimal nutrients for this work. Despite promising alternatives, the treatment of microplastics is still in its infancy. Future strategies have been identified and the number of applied measures is expected to grow exponentially in the coming years.

5. Conclusion

There is no doubt that plastic waste affects all aspects of human health and the environment due to its widespread use and slow degradability. The final destination of these compounds after entering the waters are oceans and seas, and according to studies, these compounds have a long shelf life in seawater and sediments, and by feeding marine organisms with these compounds, the health of these organisms will be endangered over time. The methods that can be used to control and reduce these compounds in the environment include determining the primary and secondary sources of microplastics, Further studies on marine plastics stored in plankton samples, adding microplastics as a routine survey variable in river and ocean basins, assessing microplastic pollution in the Antarctic and Arctic, Creation and continuous improvement of experimental methods to determine the quantity of microplastics, new techniques to evaluate the pollution of microplastics and their destruction, and international cooperation to clean up plastic pollution in the oceans can be effective solutions to control the spread of these pollutants in the marine environment.

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