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A Review of Microplastics and Their Impact on Ocean Ecosystems

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ABSTRACT

Microplastics are commonly found in many ocean ecosystems and species. They are extremely prevalent in the environment, caused by the degradation of larger pieces of plastics. However, their health impacts on different trophic levels have not been extensively studied. In this paper, we seek to examine the health impacts of microplastics on various marine and terrestrial trophic levels, including producers, primary consumers, larger marine organisms, decomposers, and also humans. In this review, we identify similar health impacts on each trophic level from microplastics, namely: tissue irritation, inflammation, and damage, stress responses, and disruption of immune and metabolic processes. This is significant as it demonstrates that microplastics have the potential to harm organisms no matter their trophic level or size. We also find that the main factor determining direct microplastic ingestion is feeding strategy. Furthermore, we determine that microplastics do not biomagnify through food chains; however, they do bioaccumulate in organisms. Additionally, we examine microplastic concentrations within many species including commonly farmed marine organisms, and also within water systems. Finally, we describe potential solutions for the problem of microplastics in natural ecosystems. Our findings contribute to the larger body of work regarding microplastics by detailing their health impacts on organisms and analyzing potential causes, correlations, results, and solutions.

Introduction

Plastics have taken over every aspect of consumer life. From plastic bags to water bottles, many common summer products utilize single-use plastics. Plastics have innumerable benefits: they are chemically stable, light and degradation resistant, can be shaped into almost anything, and are cheaply manufactured. However, the present overuse of plastics has led to an exponentially increasing amount of plastic pollution worldwide (OECD 2022). Plastic pollution is an urgent and severe problem that grows worse every day. Plastics are accumulating in the ocean due to their resistance to environmental degradation. Depending on the type of plastics, it can take a couple to hundreds or even thousands of years for plastics to decompose in a landfill or in the environment. It has been estimated that there are 75 to 199 million tons of plastic in the ocean resulting from only a few decades of accumulation (UN Environment Programme 2022). Plastics are also pervasive throughout even the most remote natural ecosystems. In fact, scientists have found plastic bags in the Mariana Trench, the deepest known place on Earth (Morelle 2019).

When plastics do finally degrade, they form extremely small plastics called microplastics. In this paper, we detail the impacts of microplastics on ocean ecosystems, humans, and potential solutions to the problem of plastic pollution.

Background

The majority of plastics are long strands of monomers linked together via covalent bonds. Collectively, these plastics are known as polyethylene. These give unprecedented physical resistance to wear and tear but also contribute to the creation of microplastics. Recently, microplastics have become an increasingly prevalent urgent problem. Data has shown that microplastics are present in almost every human and poses a variety of health concerns such as metabolic disorders, reduced fertility, and exposure to harmful chemicals (Harvard Health Publishing 2019). It is not completely understood how microplastics are created, but data seems to point towards two broad types of degradation: physical and chemical.

Physical degradation can be summarized as wave and wind abrasion, which is the force of waves and wind slamming plastics, which gradually weakens and breaks the covalent bonds that bind the monomers together (Lim 2021).

The other method of plastic degradation into microplastics is chemical degradation. There is a wide variety of chemical degradation, including photo-oxidative, thermal oxidation, and hydrolysis. Photo-oxidative is the force of sunlight adding electrons, which weakens bonds and leads to the eventual break-off of free radicals and microplastics from larger polyethylene chains. Thermal oxidation is a process similar to hydrogen embrittlement in which sunlight aids in the oxidation of open bonds on the exterior of the plastic. The addition of oxygen weakens the chain and contributes to the eventual degradation of plastics and formation of microplastics and free radicals. Hydrolysis is the process in which water gives away a hydrogen ion to impurities within the plastic. The addition of hydrogen breaks bonds, creating microplastics and free radicals. These processes are almost never independent, and the creation of microplastics is a combination of all of these factors working together.

There are 5 different types of microplastics. One of the most common types of microplastics are fragments, which account for 55% of microplastics in bay surface water and 17% of microplastics in wastewater ("Zooming in on the Five Types of Microplastics"). These are small pieces of plastics that have fragmented from larger plastics, and include microbeads. Another one of the most common types of microplastics are fibers, accounting for 27% of microplastics in bay surface water and 80% of microplastics in wastewater. These are strands of plastics and can be produced from synthetic fabric, clothing, and fishing lines. The next most common type is film, which accounts for 8% of microplastics in bay surface water and 2% of microplastics in wastewater. These are thin, flat sheets of plastics and can be produced from plastic bags and packaging. Next is foam, which accounts for 8% of microplastics in bay surface water and 1% of all microplastics in wastewater. These are thicker layers of microplastics that can be crumpled up and can be produced from polystyrene and cigarette filters. Finally, there are pellets or nurdles, which only account for 2% of microplastics in bay surface water and a tiny fraction of microplastics in wastewater. These are usually from plastic pellets from manufacturing ("Zooming in on the Five Types of Microplastics").

Microplastics, regardless of type, are extremely pervasive in many ecosystems across the Earth, especially in marine ecosystems. It is estimated that over 2000 marine species have been affected by microplastics (Sutton and Sedlak 2017). In this paper, we detail the effects of microplastics on each marine trophic level and humans, and discuss potential solutions.

Primary Producers: Phytoplankton

Phytoplankton are microscopic marine algae, and are the basis of the marine food chain. They are primary producers, and obtain energy through photosynthesis. They feed the zooplankton population, which are an indicator species for many marine habitats. Additionally, they are also essential to the carbon cycle, and therefore to humans as well. This is because they account for around half of all photosynthetic activity on Earth, and therefore half of all plant oxygen production, while only amounting to 1% of plant biomass on Earth (Pierella Karlusich et al. 2020).

Microplastics have an adverse effect on phytoplankton. A study (Mao et al. 2018) was conducted to determine the impacts of microplastics on Auxenochlorella pyrenoidosa (formerly Chlorella pyrenoidosa), a type of freshwater phytoplankton. In this study, polystyrene microplastics were exposed to the phytoplankton. Three concentration gradients, 10 mg/L, 50 mg/L, and over 100 mg/L, each with microplastic sizes of 0.1 and 1.0 µm, which were were applied to the phytoplankton. Note that the lower microplastic concentrations (10 mg/L and 50 mg/L) simulate true environmental conditions, while 100 mg/L exceeds environmental conditions.

Auxenochlorella pyrenoidosa has three growth phases. First is the lag phase, where the phytoplankton are metabolically active but not dividing. Second is the logarithmic phase, which is a period of time with exponential population growth. Finally, there is the stationary phase, where population growth slows and stops as the number of dying cells equals the number of dividing cells (Bailey 2018).

This study determined that microplastics had dose-dependent negative effects on phytoplankton growth in the earlier logarithmic phases (Mao et al. 2018). These adverse effects included reduced photosynthetic activity, unclear pyrenoids, distorted thylakoids, and damaged cell membrane, all resulting from microplastics causing physical damage and oxidative stress. Auxenochlorella pyrenoidosa only showed slight differences in the maximal inhibition ratio between the two microplastic sizes, meaning that the size of the microplastics did not strongly affect the potency of the adverse effects.

However, from the end of the logarithmic to the stationary phase, Auxenochlorella pyrenoidosa could reduce the adverse effects of microplastics through thickening the cell wall and separating microplastic particles from algae. These actions would trigger an increase of algal photosynthetic activity and growth, resulting in cell structures returning to normal. Therefore, the study confirmed that microplastics can harm but then enhance algae growth, depending on the growth phase.

Therefore for phytoplankton, microplastic size is not a strong factor, while microplastics concentration determines the magnitude of the effect on phytoplankton. Additionally, high microplastic concentrations resulted in a two phase effect on phytoplankton. From the lag to earlier logarithmic phase, microplastics caused an adverse dose-dependent effect on Auxenochlorella pyrenoidosa growth and photosynthetic activity. Then from the end of the logarithmic to the stationary phase, there was an increase of algal photosynthetic activity and growth, as Auxenochlorella pyrenoidosa could reduce the harmful effects of microplastics, resulting in cell structures returning to normal. Ultimately, microplastics with concentration levels similar to that in typical ocean ecosystems have mixed effects on phytoplankton.

Primary Consumers: Zooplankton

Microplastics also have a significant influence on zooplankton in the ocean. Microplastics adhere to zooplankton, prohibiting locomotion. In waters with high microplastic concentration, microplastics are commonly trapped between the external appendages of various zooplankton. Polystyrene beads with a diameter of 1.7 to 3.8 µm are able to cluster within the esophagus, stomach, intestines, setae, and joints of external appendages. Very small microplastics (0.4 – 3.8 µm) can become stuck between smaller external appendages. This negatively affects the ability of zooplankton to feed, reproduce, and evade predators, resulting in higher chance of early death (Cole 2019).

Ingestion of microplastics results in physical injuries and reduced feeding rates of zooplankton. Zooplankton ingest similar microplastics indiscriminately and excrete them in faucal pellets. This is a quick process that occurs in the span of only a few hours. The remaining microplastics stuck inside the bodies of zooplankton reduce the frequency of feeding, and further accumulate inside tissues and internal organs (Cole 2019). Factors that determine whether zooplankton intake microplastics and what kind, are based on the size of microplastics, the age of microplastics, the stage of life of zooplankton, and the zooplankton species. The age of the microplastics is also proportional to the amount of bacteria on the surface of microplastics, which can generate a chemosensory response that makes them more attractive to zooplankton (Botterell et al. 2019).

Additionally, some microplastics are produced with additives which create a high surface area to volume ratio, making them more vulnerable to contaminants in the ocean. These contaminants have a harmful impact on zooplankton when they are ingested, causing negative effects on growth, sexual development, fecundity, morbidity, and mortality. Moreover, these contaminants stick to microplastics when they bioaccumulate in marine organisms, resulting in higher levels of contamination over time.

One important and lesser known effect of zooplankton is their impact on deep sea habitats and oceanic microbial life. The death of zooplankton at the surface, and the downward drift of dead animals, showers the deep sea in what is called "marine snow," which is a principal food source of deep sea habitats. In addition to dead zooplankton, the waste products of zooplankton also serve as nutrient sources for a diverse spectrum of oceanic microbial life. The waste also helps recycle critical elements such as carbon and nitrogen in deep sea environments. The loss of zooplankton would be harmful for deep sea habitats, potentially endangering species in the bathyal, abyssal, and hadal zones of the ocean (US Department of Commerce, National Oceanic and Atmospheric Administration 2019).

Zooplankton are also extremely important intermediary species that transfer energy from producers (like plankton) to larger marine animals that humans then consume. Zooplankton population is often utilized as a key indicator of environmental health when studying a specific habitat. Furthermore, the larger animals that we harvest from the ocean are carnivorous, and thus, we are completely reliant on zooplankton to maintain the populations of critical species. A continuous influx of microplastics into the ocean from industrial manufacturing and plastic degradation will result in a decline of zooplankton population, leading to harmful impacts on all marine species of higher trophic levels. Critical species, such as Peruvian anchovies or grass carp, will also see population declines. For example, for Peruvians, the mass dieoff of zooplankton would effectively wipe out 2% of their economy, 2.5 billion dollars in annual GDP, and 232,000 jobs (Lindeque et al. 2021). Economies across the globe would be massively impacted. Even more significant is the harmful effect zooplankton population decline will have on ocean ecosystems. It will cause a cascading effect across all trophic levels, leading to a decrease in marine species population, biodiversity, and ecological resilience

Larger Marine Organisms: Consumers and Predators

Microplastics can also affect larger marine organisms through direct consumption, passing on from prey to predator. A study (Mazlan et al. 2022) was conducted about microplastic contamination in New Zealand, one of the least polluted countries in the world. The study examined microplastic concentrations in green-lipped mussels and other sea organisms important to New Zealand's food industry and economy. Using 10% potassium hydroxide, researchers were able to chemically digest tissues and isolate microplastics. This was effective because polymers such as polyethylene terephthalate, high-density polyethylene, low-density polyethylene, polypropylene and polystyrene are relatively resistant to potassium hydroxide. Additionally, Fourier-transform infrared spectrometry was performed to identify the types of microplastic particles present in the tissues.

Researchers found a high number of microplastic fragments in the digestive tracts of New Zealand green-lipped mussels and tarakihi fish. These microplastics could be potentially passed onto humans who eat or buy these animals as products.

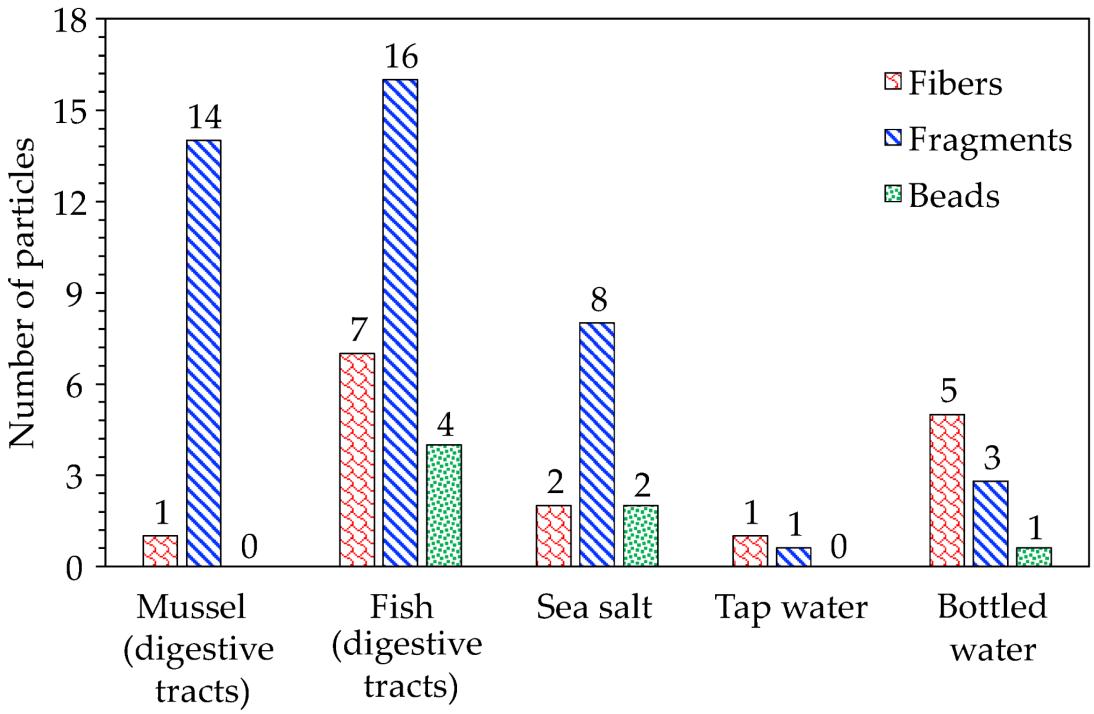

Figure 1. Number of microplastic particles in certain marine species and water (Mazlan et al. 2022)

The data indicates that microplastics accumulate in the digestive tracts of fish and mussels. Although they are present in relatively low concentrations in the different kinds of water, as they go through those animals' digestive tracts where the filtration process takes place, a large number of those fragments remain instead of being excreted (Mazlan et al. 2022). The steady accumulation of microplastics will take up room in the stomach, clog up the digestive system, and prevent food from being readily digested.

Fortunately for consumers and predators on higher trophic levels, microplastics do not biomagnify through marine food webs. Biomagnification is when a concentration of a toxin or particle in tissues of organisms increases at successively higher levels in a food chain. This is due to larger animals consuming many smaller organisms, which all have a toxin in their tissues, causing a buildup of this substance in organisms further up the food chain. However, since microplastics do not biomagnify, higher trophic levels do not necessarily have higher concentrations of microplastics than lower ones. This was shown through systematic analysis of microplastic concentration for species on different trophic levels (Walkinshaw et al. 2020). Below is a figure demonstrating the study's findings.

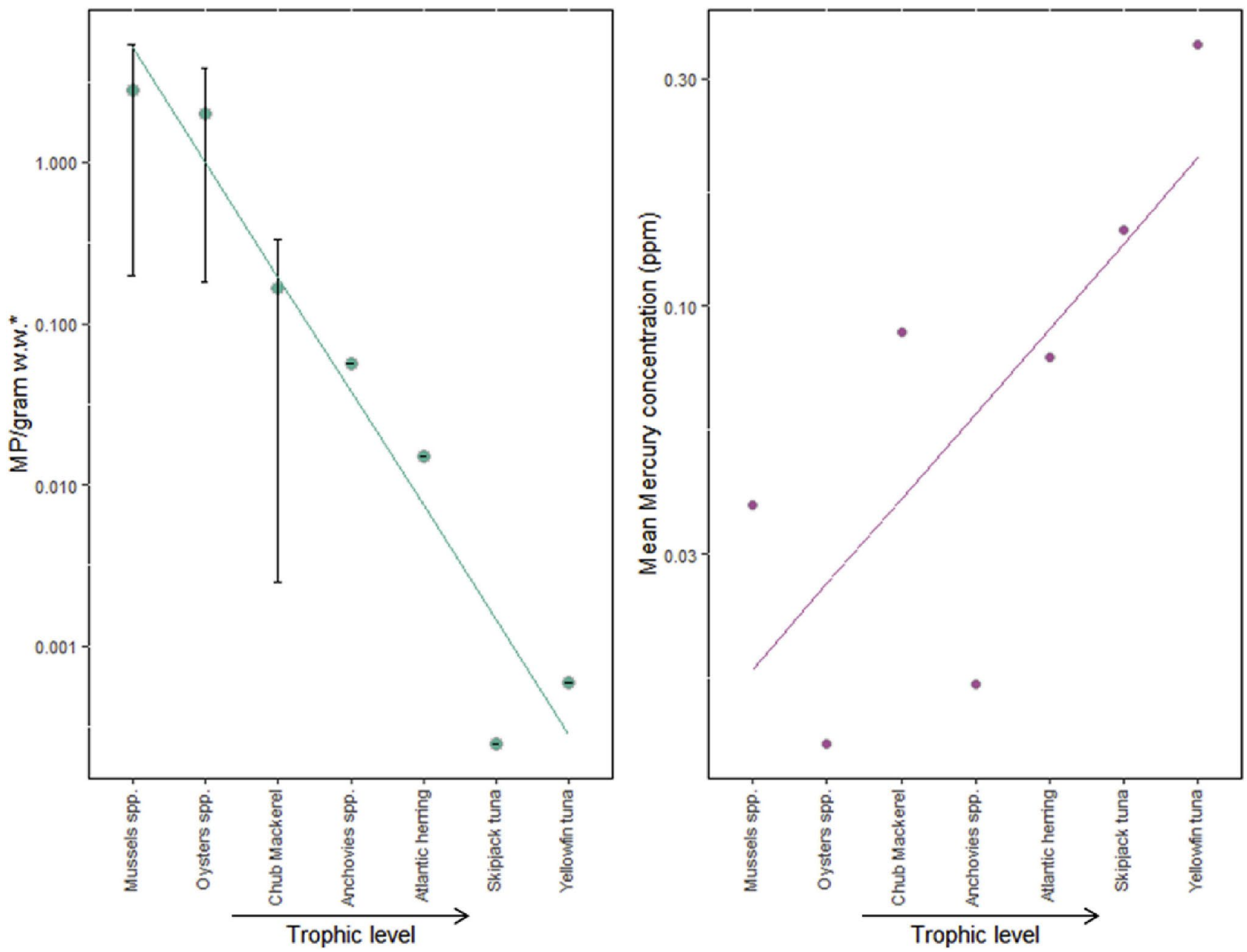

Figure 2. Microplastic and mercury concentrations throughout trophic levels (Walkinshaw et al. 2020)

According to the graph on the left, the amount of microplastics per gram of wet tissue is inversely correlated with trophic level, disproving microplastic biomagnification. This is dissimilar to the graph on the right, demonstrating a positive correlation between mercury concentration and trophic level, meaning that mercury biomagnifies.

Therefore, species in higher trophic levels will most likely have a lower relative amount of microplastic concentration in their bodies. Thus, the lowest trophic levels, which are often the most important to a marine ecosystem, are at the highest risk of contamination. This is also evident from the fact that microplastics more easily adhere to smaller marine organisms such as zooplankton (Walkinshaw et al. 2020).

The study (Walkinshaw et al. 2020) that concluded this used a semi-systematic review of scientific literature in the field, including microplastic analyses for fish, shellfish, crustaceans and macroalgae. The ten most caught marine species: Grass Carp, Silver Carp, Cupped oysters, Common carp, Japanese carpet shell, Nile tilapia, Whiteleg shrimp, Bighead carp, Crucian carps, Catla, were all analyzed. The importance of examining commonly caught and aquacultured marine organisms is that microplastics in those organisms can potentially be transferred to humans through direct consumption of seafood. It is crucial that microplastics concentrations are known for these commonly caught and farmed marine species. This meta-analysis study analyzed the combined average amount of microplastics for most commonly caught fish, shellfish, and crustaceans.

For marine fish, the studies analyzed gave a combined average amount of microplastics per organism of 2.5 ± 1.3 microplastics per individual for Common carp, 1.9 ± 1.0 microplastics per individual for Crucian carps, and 3.8 ± 2.0 microplastics per individual for Silver carp. An average of 16% of individuals of Nile tilapia had consumed microplastics. The percentages of each species that were seen with microplastics in their gastro-intestinal tract were: 0.9% Peruvian anchovy; 9.4% Skipjack tuna; 24.5% Jack and Horse mackerels; 8.8% Atlantic herring; 23.3% Pacific chub mackerel; 23.4% Yellowfin tuna; 2.8% Atlantic cod; and 76.6% Japanese anchovy (Walkinshaw et al. 2020).

For shellfish, cupped oysters (Crassostrea spp.) and Japanese carpet shell (Ruditapes philippinarum) are among the most commonly aquacultured shellfish species worldwide. For Cupped oysters, the average result reported ranged from 0.18 to 3.84 microplastics per gram of wet tissue, and for the Japanese carpet shell, the average reported result ranged from 0.9 to 2.5 microplastics per gram of wet tissue. As for shellfish that were mussels of the family Mytilidae, the amount of microplastics found in sea mussels in their natural environments varied drastically, with ingestion ranges varying from 0.2 to 5.36 microplastics per gram of wet tissue (Walkinshaw et al. 2020).

Crustaceans include shrimp, crabs, lobsters, crayfish and prawns. Brown shrimp (Crangon crangon) are a commercially important crustacean fished in the eastern Atlantic and Mediterranean Sea, and had an average of 0.68 ± 0.55 microplastics per gram of wet tissue. Additionally, 63% of the 165 shrimp analyzed contained microplastics (Devriese et al. 2015). Green tiger prawn (Penaeus semisulcatus), which is commercially prevalent in East Africa and Asia, was found to have ingested an average of 7.8 particles per individual, which is equivalent or 1.5 particles per gram of wet tissue, in the Musa estuary, Persian Gulf (Abbasi et al. 2018). Nylon fibers were observed in the stomachs of 5.93% Plesionika narval (narwhal shrimp), which constitute an important fishery in the Aegean Sea. However, these fibers may result from the fishing method (Walkinshaw et al. 2020).

This study further concluded that the two main ways for marine organisms to ingest microplastics are direct ingestion from the natural environment or indirect ingestion from prey. Dietary strategy is an important characteristic that could determine microplastic ingestion in fish. Planktivores (organisms feeding on plankton) are more likely to consume microplastics directly from the natural environment. However piscivores (carnivorous organisms which prey on other fish) would probably consume microplastics mainly through hunting and eating prey or accidental ingestion while feeding.

Direct ingestion of microplastics, specifically the amount, type, and size of microplastics, is a result of feeding strategy. Discriminate feeders ingest microplastics based on factors such as color and size when they resemble prey, or accidentally while feeding. This was demonstrated in a study (Ward et al. 2019) where eastern oysters (Crassostrea virginica) and blue mussels (Mytilus edulis) were offered different size and shape microplastics. It was found that these two species ingested microplastics preferentially based on the physical characteristics of the microplastic. On the other hand, indiscriminate feeders show no selection in the matter that they directly ingest, ingesting prey in proportion to their availability in the environment. Therefore, indiscriminate feeders ingest microplastics randomly.

Indirect ingestion occurs when organisms consume prey that have already ingested microplastics which have accumulated inside the prey. This can occur to all species, regardless of trophic level, or feeding strategy. Trophic transfer of microplastics was demonstrated in a study (Farrell and Nelson 2013), where shore crabs (Carcinus maenas) were fed blue mussels (Mytilus edulis), which had previously been fed 0.5 µm PS microplastics. With each crab being fed only one mussel, the microplastics were detected in the internal organs of the crabs, including the stomach, hepatopancreas, ovary, gills and haemolymph (Farrell and Nelson 2013).

Moreover, data indicates that microplastics do bioaccumulate in organisms' intestines and tissues. This means that within an organism, the concentration of microplastics will increase with time. Due to microplastic ingestion, microplastic bioaccumulation is mostly due to feeding strategies of marine species rather than trophic level, meaning that microplastic bioaccumulation can occur regardless of trophic level (Miller et al. 2020).

Just like in smaller marine organisms, microplastics also have adverse effects on larger consumers. Microplastics inhibit growth and development, have a toxic effect on marine organisms due to the accumulation of toxins on their surfaces, and cause genetic damage. This results in reduced food intake, delayed growth, oxidative damage, and abnormal behavior (Li et al. 2021). Additionally, nano-scale microplastics can pass the biological barrier and accumulate in tissues, resulting in the generation of reactive oxygen species, negatively impacting lipid metabolism, and possibly further affecting life at the molecular level. Fish that ingested nano-sized polystyrene particles through trophic transfer had significant differences in body mass, cholesterol percentage in muscle and liver, and other metabolic parameters (Li et al. 2021).

The first main effect of microplastics on larger marine organisms is the inhibition of growth and development. When microplastics are taken into the body by larger marine organisms, they will accumulate in the digestive tract and block it, resulting in reduced feeding impulses, decrease in feeding capacity, and reduced energy reserves in the body, all negatively impacting the growth of marine life (Li et al. 2021). For example, polystyrene microplastics in the sediment can greatly reduce the growth of blow lugworms (arenicola marina), and the degree to which growth is stunted is positively correlated with the concentration of microplastics. Microplastics also interfere with the feeding and growth of the sea urchins, as observed with the collector urchin (tripneustes gratilla), but do not have a lethal effect. Polystyrene microplastics also severely decrease the energy reserves of fish and mollusks as witnessed by Korean rockfish (Sebastes schlegelii) and Bivalve molluscs, reducing the nutritional quality of these organisms. Finally, microplastics cause increased energy consumption and decreased growth rate of mussels as observed with the Mediterranean mussel (mytilus galloprovincialis) (Li et al. 2021).

The second significant effect of microplastics on larger marine organisms are toxicological effects, which result in reproductive harm of marine life (Li et al. 2021). For example, under the influence of polystyrene microplastics, oysters will ovulate significantly less egg cells and have reduced sperm motility levels, as observed by the Pacific oyster (thecrassostrea gigas). Furthermore, after the microplastics enter the biological tissues and organs of marine fish, they will trigger a series of immune responses. For example, polyvinyl chloride and polyethylene microplastics with particle sizes of 40 to 150 µm can cause oxidative damage to the white blood cells of fish as evidenced by Gilt-head bream (sparus aurata) and European seabass (dicentrarchus labrax), resulting in immunotoxicity. Below is a chart detailing the toxicological effects of different microplastic types and concentrations on different fish species (Li et al. 2021).

fish species	microplastic type	particle size	concentration	toxicological effects
Pomatoshistos microps	PE	1～5µm	184µg/L	AChE activity decrease
Acanthochormis Polyacanathus	PET	1～2mm	0～0.86mg/L	growth decrease
Dictrarchus labrax	PE	10～45µm	10～100pcs/mg	mortality increase
Dictrarchus labrax	PVC	＜0.3mm	0.1% (quality ratio)	inflammation
Dictrarchus labrax	polymer	1～5µm	0.69mg/L	swimming speed decrease
Oryzias Lapites	PE*	<1mm	8µg/L	male: abnormal proliferation of sperm cells
Carrassius Carassius	PS	(24.7±0.2) nm	130mg	vitality decrease
Daniorerio	PS	(24.7±0.2) nm	1.5×10^{13}pcs/L	body length decrease
Daniorerio	PE,PP,PA, PVC	70µm	1.0mg/L	intestinal injury

Figure 3. Toxicological effects of microplastics on fish (Li et al. 2021)

Finally, microplastics can cause genetic damage. Studies have shown that microplastics absorb polycyclic aromatic hydrocarbons, which can come from wood-burning and combustion of biofuels. This causes immunotoxicity, neurotoxicity and genotoxicity in mussels, and can result in genetic damage, as observed with Mediterranean mussels (M Galloprovincialis) (Li et al. 2021). Currently, however, more research needs to be conducted regarding the effects of genetic damage from microplastics on marine life, as there are still very few studies concerning this topic.

All in all, we can see that microplastics have many adverse effects on larger marine organisms such as fish, shellfish, mollusks, and crustaceans. These negative effects can lower the populations of marine organisms, possibly leading to the endangerment or even extinction of marine species. These harmful effects also serve to decrease biodiversity and resilience of species' populations. Furthermore, since microplastics are present in commonly caught and aquacultured fish, shellfish, mollusks, and crustaceans, they can be transferred to humans through direct consumption of seafood.

Humans

Numerous studies have examined the concentration of microplastics in bodies of freshwater, tap water, and bottled water. The results range from 10^{-2} to 10^{8} microplastics/m^3 of water varying across all sample sizes and water types. Below is a figure containing box and whisker plots from a meta-analysis study examining microplastic concentration in freshwater.

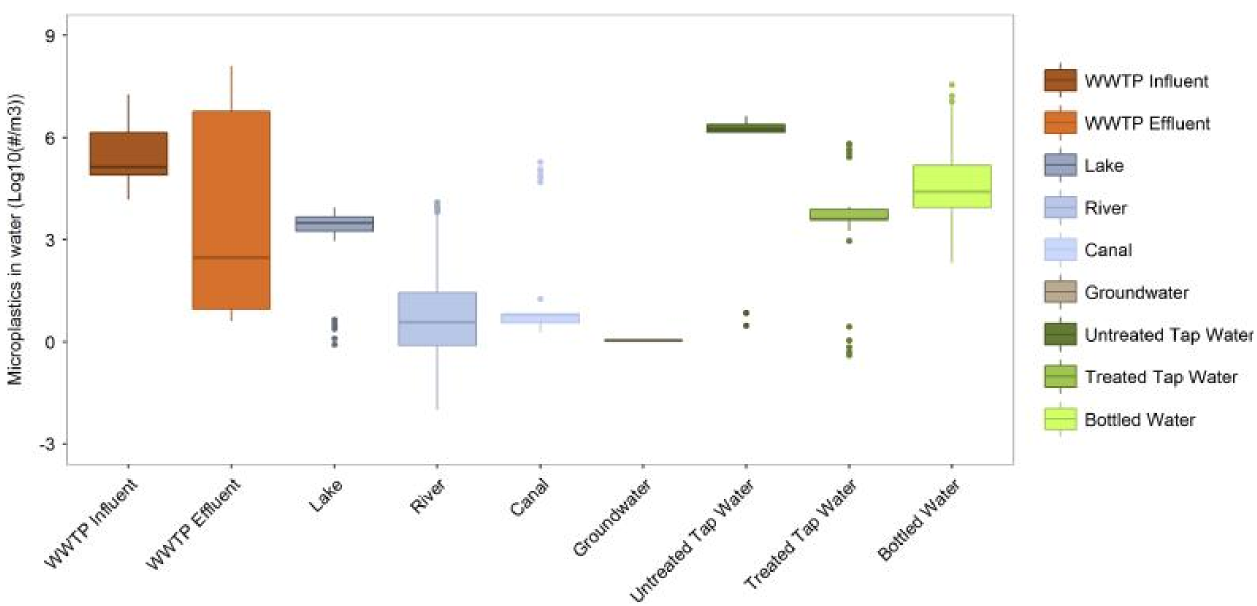

Figure 4. Concentrations of microplastics in various water types (Koelmans et al. 2019)

The relatively high amount of microplastics in some sources such as bottled water and tap water highlights the risk of humans ingesting large amounts of microplastics. Furthermore, even to humans, microplastics pose health risks when ingested.

With the size categorization, the smallest microplastics, which can be nanometers wide, may cross the blood-brain barrier and can go into cells, causing cellular damage to all animals, including humans. Bigger microplastics can cause irritation and inflammation of lung tissue, and can lead to cancer (Carrington 2022b).

Many studies have found that microplastics are found everywhere within humans. A 2021 study on Brazilian autopsy samples found microplastics in 13 out of the 20 samples. Furthermore, a study of lung cancer patients in 1998 found that 97% of the samples from cancerous patients had plastic or cotton fibers in them, and 83% for non-cancerous patients (Carrington 2022b). This correlates inhalation of microplastics with increased risk of lung cancer. Finally, a 2022 survey detected microplastics in the blood of almost 80% of the people surveyed. The scientists analyzed blood samples from 22 anonymous donors who were all healthy adults, and found plastic particles in 17 of them. Half the samples contained PET plastic, a third contained polystyrene, and a quarter of the blood samples contained polyethylene (Carrington 2022a).

The health impacts of microplastics are both severe and broad. Studies have found that ingested microplastics can irritate, and damage tissue, cause stress responses, induce reproductive and developmental toxicity, cause immune dysfunction and metabolic disruption, cause neurodegenerative diseases, and cause chronic inflammation, which can lead to cancer (Hill 2020).

Furthermore, the health impacts of microplastics is not only from the microplastic itself but also from the toxins accumulated on microplastics from its environment. These microplastics and toxins themselves can bioaccumulate in tissues and in the digestive organs of many organisms, including humans. Furthermore, the accumulation of toxins on microplastics increases the toxicity of organic pollutants in the environment by a factor of 10 (Tel-Aviv University 2022). This is due to microplastics absorbing and concentrating toxic organic substances, increasing their toxicity by a factor of 10. Therefore, even low concentrations of environmental pollutants, which are non-toxic to humans, can significantly increase in toxicity and become toxic to humans, once they adsorb to microplastics. This will cause severe harmful impacts on humans who are exposed to toxic microplastic contaminated food and drink (Tel-Aviv University 2022).

All in all, microplastics have many harmful health effects on humans such as tissue damage and irritation, stress responses, reproductive and developmental toxicity, immune dysfunction and metabolic disruption, neurodegenerative diseases, and chronic inflammation, which can lead to cancer. Moreover, microplastics that adsorb and accumulate toxins can increase the toxicity of the organic pollutants by a factor of 10, which is extremely harmful for human health.

Decomposers

The role of the decomposers is to break down dead organisms, transform dead tissues into nutrients, and send those nutrients back to the soil for primary producers to consume. Natural decomposition in the food webs do not relate that much to microplastics since most natural bacteria do not dissolve any type of plastic that exists in the world today.

Knowledge on how microplastics impact soil organic matter decomposition and the priming effect remains limited. Soil priming effect is a short-term change in organic matter decomposition that occurs when something is added to the soil, which can accelerate or slow decomposition, and release or immobilize a large amount of carbon or nitrogen in the soil (Ferraz-Almeida 2022). A study (Xiao et al. 2021) investigated the impact of microplastic concentrations (none, low [0.01% mass], or high [1% mass]), addition of labile C (glucose), and addition of rice straw on soil organic matter decomposition and priming effect. It is known that the addition of labile C (glucose) or rice straw increases the speed of organic matter decomposition and improves the amount and effectiveness of soil nutrients (Jin et al. 2020).

However, compared to no additions or the additions of glucose or rice straw, the addition of microplastics reduced the speed of soil organic matter decomposition. Even between the low and high dosage of microplastics, soil organic matter decomposition was much lower under high microplastic dosage than under low microplastic dosage. Furthermore, compared to soil without the addition of rice straw or glucose, the total amount of CO_2 from soil organic matter under low microplastic concentration declined by 13.2% and 7.1% after straw and glucose addition, respectively (Xiao et al. 2021). Therefore, microplastics inhibit soil carbon sequestration, the process of transferring CO_2 from the atmosphere to the soil in the form of organic carbon (Cherlinka 2023), especially with the addition of rice straw and glucose.

With glucose and rice straw addition, the glucose-induced priming effect was up to 10 times stronger in the presence of low microplastic concentrations compared to that in high microplastic concentrations. This means high concentrations of microplastics result in up to 10 times slower soil organic matter decomposition compared to low concentration microplastics under the addition of glucose to induce a priming effect. However, under the presence of microplastics, glucose induced a negative priming effect on rice straw decomposition, meaning that glucose reduced the rate of rice straw decomposition in the presence of microplastics (Xiao et al. 2021).

Therefore, the study conclusively determined that the presence of microplastics hinders the ability of decomposers to break down organic compounds in the soil. This effect is quite significant, as even comparing high to low microplastic concentrations, the decomposers were much less efficient under high microplastic concentrations in degrading organic matter.

This is significant as the increased concentration of microplastics in all ecosystems will considerably affect decomposers, leading to a major disruption in natural organic nutrient cycling (Simon 2021). The interruption of nutrients and energy cycling, which are essential for synthesizing organic matter in all trophic levels, will cause devastating effects on an ecosystem. This is because with a slower decomposition rate due to microplastic contamination, the nutrient pool of an ecosystem will be depleted much more quickly, starving plants and animals of necessary nutrients. This results in a decrease in species populations, biodiversity, and species resilience, all significantly damaging the ecosystem (Mori et al. 2020).

Potential Solutions

The main way to prevent the harmful impacts of microplastics in both animals and humans, and to entire ecosystems, is to convince or elect policymakers to pass laws prohibiting the manufacturing of microplastics, and use of microplastics in products. This systemic change needs to occur in order to stop the influx of microplastics into ecosystems all over the world. All countries need to collaborate and develop international legally binding treaties to combat this issue.

Fortunately, there has already been progress in the elimination of microplastics from daily products. In 2018, the European Union passed a law banning microplastics in cosmetic products, along with giving Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), the right to regulate in the EU (Kentin and Kaarto 2018). Citizens need to use their voting power to elect policymakers that will support and fund the fight against plastic pollution and microplastics. Individuals should also inform their relatives, friends, and colleagues about such issues, and persuade them to vote in the same way.

As for dealing with plastic waste, current methods include physical treatments such as heating or thermal oxidation, mechanical treatments such as crushing and grinding, chemical treatments such using acid or salt, recycling, and landfill dumping. However, physicochemical methods to degrade plastics all have limited efficiency and result in release of hazardous metabolites, greenhouse gasses, or by-products in the environment (Shilpa et al. 2022). Moreover, recycling can be ineffective if not performed correctly, and landfill dumping may result in plastic leaking into the environment from open dumping sites (Reality 2019).

One potential environmentally friendly solution to this problem of plastic waste is biodegradation (also called microbial degradation), including bacterial, fungal, and algal degradation (Shilpa et al. 2022). Biodegradation is an environmentally friendly treatment method because it does not result in any hazardous by-products (Moharir and Kumar 2019). Some bacteria have recently been proven effective in breaking down certain types of plastic. For example, in 2016, Ideonella sakaiensis, a species of bacteria, was discovered degrading plastic at a plastic waste site in Japan. Ideonella sakaiensis is capable of using plastic polyethylene terephthalate (PET) as both an energy and carbon source by breaking down and consuming PET.

Ideonella sakaiensis anchors itself to the surface of the plastic with its flagellum, and releases PETase enzymes that come into contact with the plastic's surface. This PETase enzyme can degrade PET plastic into MHET acid and ethylene glycol. The MHET acid is then further broken down, and its components are taken up and used by Ideonella sakaiensis and other bacteria to survive (Yoshida et al. 2016).

In approximately 6 weeks, Ideonella sakaiensis is able to replicate and break down a thin 0.2 mm film of low-crystallinity (soft) PET. However, the enzyme responsible for degrading PET, was shown to degrade high-crystallinity (hard) PET approximately 30 times slower (180 weeks or more than 3 years) than low-crystallinity PET (Yoshida et al. 2016). Unfortunately, the majority of manufactured PET is highly crystalline, like plastic bottles. Thus, limited degradation efficiency is a major setback for biodegradation of plastics becoming feasible at significant scale (Mohanan et al. 2020).

Therefore, solutions like the genetic optimization of the PETase enzyme will likely need to be implemented, before large scale applications of the PETase enzyme from Ideonella sakaiensis are used to degrade PET in recycling programs. In fact, the PETase enzyme has already been genetically modified and combined with a second enzyme MHETase, to break down PET six times faster (Carpenter 2021). This also results in PETase being able to degrade PEF (polyethylene furanoate) plastics (Yoshida et al. 2016). Furthermore, microbial degradation can be optimized and combined with physicochemical methods to achieve significant results in getting rid of plastic pollution in an environmentally friendly manner (Shilpa et al. 2022). However, more research will have to be conducted in this area before biodegradation of plastic waste becomes feasible.

Finally, individuals can combat the problem of plastic pollution and microplastics by being conscious of their plastic waste. Electing to not use single use plastics or choosing to recycle plastics helps combat the problem of plastic pollution ending up in natural ecosystems or environments. This means that less plastics will degrade into microplastics, therefore benefiting ecosystems by lessening microplastic contamination in the environment.

All in all, the most an individual can do to combat the problem of microplastic contamination is to use their voting rights as citizens to elect politicians and policymakers that are conscious of the plastic pollution issue. Individuals should also be conscious of what plastic products they buy and use, especially single use plastics. They should also strive to recycle plastics so they don't end up in landfills and eventually into the natural environment. In terms of scientific fields, more research should be done on plastic degrading bacteria such as Ideonella sakaiensis and its PETase enzymes. If more efficient plastic degrading bacteria are discovered or superior genetically modified versions of current bacteria are created, plastic degrading bacteria could be implemented in large scale plastic recycling programs.

Discussion

Our study has reviewed the negative effects of microplastics across all trophic levels in marine ecosystems. We examined literature describing microplastic concentrations in all trophic levels, as well as microplastic ingestion in relation to trophic level and feeding strategy. We also found that the main factor determining direct microplastic ingestion was feeding strategy. Furthermore, we determined that microplastics do not biomagnify through food chains, however, they do bioaccumulate in organisms. Moreover, we examined the surprisingly high concentrations of microplastics in freshwater, and their impacts on human health. Finally, we investigated potential solutions to plastic and microplastic waste.

In our analyses of all marine ecosystem trophic levels, also including humans, we found similar health effects on many species, namely: tissue irritation, inflammation, and damage, stress responses, and disruption of immune and metabolic processes. Microplastics also had a more severe effect on smaller organisms such as zooplankton, due to microplastics constituting a larger percent of body mass when ingested. These effects on smaller organisms like zooplankton included physical injuries, delayed growth, and reduced food intake. For medium sized organisms like fish, shellfish, and crustaceans, the effects of microplastics included delayed growth, reduced food intake, oxidative damage, and abnormal behavior. For humans, microplastics ingestion caused damage and inflammation of tissues, interruption of various metabolic processes, and an increase in the occurrence of various diseases like cancer.

If nothing is done to prohibit the production of microplastics or combat this issue, these negative effects will only become worse. The continued accumulation of microplastic contamination in the environment will lead to a snowball effect, resulting in harmful widespread impacts across many ecosystems. This includes the endangerment or extinction of many species, and severe decreases in biodiversity and species resilience.

All in all, microplastics have negative effects on almost all organisms, regardless of trophic level or species, which have noticeably similar aspects. The impact of microplastics on ecosystems and the environment as a whole is extensive and significant. These concerns ought to be immediately addressed by authorities and policymakers, who should take action to prevent the production of microplastics and facilitate the cleanup of plastic pollution.

Future Research Recommendations

Our future research recommendations include determining the long term effects of microplastics in the human body. Some research has been conducted on the health effects of microplastics, but no study has determined the long term health impacts on humans. A study pertaining to this topic will be difficult to conduct, but ultimately extremely beneficial for our knowledge regarding the various and complex health impacts of microplastics.

Additionally, further research must be conducted about the health effects of low concentration doses of microplastics on human health. Studies have found that high microplastic dosage can irritate, inflame, and damage tissue, cause stress responses, induce reproductive and developmental toxicity, cause immune dysfunction and metabolic disruption, and is correlated with cancer. However, no research has been conducted on the health impacts of low doses of microplastics. A study about this topic will be extremely useful because humans are constantly exposed to low concentration doses of microplastics every day.

Finally, additional research should be conducted in the area of plastic biodegradation before it becomes feasible at a large scale. Currently, the mechanisms in which bacteria, fungi, and algae degrade plastics are not fully understood, and further research can allow us to discover more efficient methods of biodegradation. Moreover, since efficiency is the largest problem for plastic biodegradation, further research is needed to discover ways to improve plastic biodegradation efficiency.

Conclusion

It is absolutely critical that we confront the issue of plastic pollution immediately. It is already having a measurable negative effect on many aspects of critical ocean ecosystems. If left unchecked, plastic pollution could very easily spiral out of control. Keystone species will be endangered and go extinct, leading to entire ecosystem collapse. Plastic pollution has a very concrete impact at every trophic level, and to maintain the status quo of relatively little action against plastic pollution brings us dangerously close to the collapse of our ecosystems. This will have a very real impact on our food resources and by extension the lives of those who depend on the ocean for their livelihoods. Over 3 billion people globally depend on the ocean, so plastic pollution affecting marine ecosystems is catastrophic (OECD 2022). Estimated damages from oceanic plastic pollution are estimated to be in excess of 4.2 billion USD annually (Deloitte 2019). We must eliminate single-use plastics and curb our pollution of ocean habitats. Moreover, we must make a significant effort to reverse our impacts on the ocean through clean-up efforts and the development of proper disposal and sanitation systems throughout the world.

We urge our readers to utilize their power as concerned consumers and citizens to use one's individual power to push our society away from plastics. By making smart consumer choices, one can not only reduce your individual plastic pollution footprint, but also send a message to companies producing significant plastic pollution that the general population cares about this issue. Due to the rising interest in plastic pollution there is always new legislation and discussion around plastic pollution. Therefore, individuals can write to local representatives, discuss with friends and family, and make concern for the environment a key voting issue. As a society, we should choose to elect politicians and policymakers that acknowledge and will take action on this issue. Together, we will be able to minimize our impact on the ocean ecosystems and work towards reversing the damage that we have already done to the environment.

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