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Chapter- 19

Impacts of Microplastics on Zooplankton

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Abstract:

In the aquatic food chain, microplastics (MPs) are ubiquitous. The presence of microplastics in water and the physicochemical properties of water can likely affect aquatic biota. The physicochemical environment determines the structure of zooplankton community. The pollution of aquatic ecosystems by microplastics is widespread. Aquatic zooplankton and various larger animal species (reptiles, birds, mammals) have been affected due to consumption of plastic fibres through food chains. Concentration of aquatic pollution increasing day by day with microplastics resulting from urban sewage discharges, industrial effluents, and anthropogenic activities. Microplastics are absorbed by fish that consume plankton, which is amplified by other organisms. In total, we have surveyed 57 research papers on microplastics in zooplankton. Zooplankton diversity of an area can be used to assess water contamination, particularly nutrient-rich eutrophication of that particular area. Microplastics may interfere with the production of endocrinological hormones in humans. In future, this will be a great hazard to human beings. Microplastic (<5mm in length) may be polyethene or polypropylene or polystyrene in nature and may be white or red or blue in colour. The study examines the water, the importance of zooplankton to the aquatic ecosystem, and the microplastic concentration report. As a result of this assessment, national and international authorities will be able to assess a range of stakeholders, make decisions and build policies that will benefit many stakeholders.

Introduction:

Aquatic, microscopic zooplankton can swim in a vertical position and make dynamic movements but can not navigate or move against a powerful stream (Odum, 1996; Mukherjee, 2020). Biological communities depend heavily on them because they influence the majority of aquatic ecosystems' functional features, including food chains and matter cycling (Murugan et al., 1998; Karmakar, 2021). Polluted waters can be improved and the quality of the environment monitored with zooplankton bioindicators (Dadhick and Saxena, 1999; Bera,

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2021). Water bodies can be compared to identify contaminants by comparing their quantity, variety, structure, size, and reproduction of zooplankton (Sharma and Sharma, 2017; Mukhopadhyay et al., 2000; Saha & Sarkar, 2022). Industry's expansion, rising energy consumption, irresponsible destruction of natural resources, environmental pollution and increased garbage disposal have all contributed to the increase in garbage disposal over the past few decades (Gautam et al., 2016; Bhattacharya et al., 2016; Samal et al., 2017; Chakraborty et al., 2019; Mondal et al., 2022).

The world's oceans are becoming increasingly polluted by plastic. Plastic is one of the world's most serious waste disposal issues (Bhattacharyya et al., 2022; Madhu et al., 2022). Plastics Europe estimates that approximately 5% of annual global production, or 360 million tonnes in 2018, will end up in the ocean, accounting for the vast majority of marine debris (Derraik, 2002). When plastic enters the ocean, it breaks down into tiny pieces known as microplastics (less than 5 mm), which then break down into nano-plastics (less than 100 nm) (Arthur et al., 2009). Microplastics (MPs) are primary particles formed in tiny sizes, such as granulates used in cosmetics, washing powders, cleaning solutions, or pellets (Fendall and Sewell, 2009). MPs become common as a result of their endurance and may take decades to disintegrate (Moore, 2008; Barnes et al., 2009; Aytan et al., 2020).

Once MPs are eaten by zooplankton, they may get into the food chain and have toxic effects on the environment because they soak up toxic, persistent, and bioaccumulative pollutants (Setala et al., 2014; Martins and Sobral., 2011). Some research (Steer et al., 2017; Botterell et al., 2019) has shown that filter feeders and zooplankton eat MPs. This means that pollutants linked to MPs may enter human diets through the food chain (Zarfl and Matthies, 2010). Experiments have shown what happens to zooplankton when they eat MPs. Their reproduction, survival rates, growth, eating habits, and life cycle are all affected (Botterell et al., 2019). Kvale et al. (2021) say that when zooplankton eats MPs, it affects the ocean's biological rates related to dissolved oxygen.

The soil and water ecosystems are constantly exposed to dangerous organic and inorganic compounds from both man-made and natural sources. Some network variables affecting water quality are temperature, pH, the amount of oxygen in the water, etc. Limnological factors can have different effects on aquatic life in many ways. Most of the time, limnological and biological standards are used to see if water quality meets standards and laws. When these things are too high, they could hurt aquatic life and people's health (Mukhortova et al., 2021). The data from many peer-reviewed articles and later studies on the estuary ecosystem showed that MPs, zooplankton assemblages, and limnological parameters greatly affect the water quality and trophic condition, which may affect the ecosystem's ability to work.

Materials and Methods:

There has been a search conducted of the scientific literature utilising the search engines Google Scholar, Internet Archives, and Academia Edu, along with keywords such as Zooplankton Diversity, Microplastics and Coastal Estuarine. We studied manuscripts between

December, 2021 to October, 2022. All remaining relevant references were reviewed, and spurious hits, such as papers without microplastics and zooplankton, were ignored. Microplastic consumption by zooplankton in the laboratory is mainly investigated from the perspective of feeding, reproduction, growth, development, and lifespan. 57 articles regarding zooplankton and microplastics were surveyed for our review works.

Diversity of zooplankton and its role:

Numerous zooplankton species, including *Daphnia, Cyclops, Cypris*, and *Brachionus*, were frequently reported in the surveyed articles. Most scientists have found several groups of zooplankton. Of these, Rotifera, Cladocera, and Copepoda are the three hugest. *Brachionus* represented Rotifera by the genera *Keratella, Asplanchna, Polyarthra, Lecane*, and *Filina*, Cladocera by the genera *Diaphanosoma, Ceriodaphnia, Daphnia, Moina, Bosmina*, and *Acroperus*, and Copepoda by the genera *Heliodiaptomus* and *Mesocyclops* (Patra and Madhu, 2009; Midya et al., 2018; Chakraborty and Halder Mallick, 2020).

The Bay of Bengal had an intra-seasonal study on zooplankton abundance to clarify the area's fertility as a new fishery site. The 22 species that make up the zooplankton population. When it came to both the number of species and their abundance, Copepoda dominated the landscape. Copepods, protozoan zooplankton, arrow worms, larvaceans, cnidarians, ostracods, and the liaceans were also widely spread in these regions (Sahu et al., 2021). In total, 53 species of zooplankton were found in estuarine waters. These species were calonoidia (13), ciliate (8), cyclopodia (6), crustacean larval forms (3), harpacticoida (3), foraminifera (3), mollusca (2), chaetognatha (2), and siphonophores. Copepodite, ctenophore, doliolids, isopods, ostracoda, cladocera, ctenophore, decapoda, and fish larvae were also found, but in smaller numbers. It was found that zooplankton density peaked in the summer but decreased during monsoons. However, during the rainy season, their numbers are reduced by the abrupt drop in temperature and mineral dilution (Mukherjee, 2020).

Quantitative research on the physicochemical properties of zooplankton shows that the number of zooplankton changes a lot from season to season (Patra and Madhu, 2009; Dutta et al., 2014). It has been found that the physical and chemical properties of a body of water greatly affect how many zooplankton live there. Also, it has been noticed that seasonal changes have a big effect on how physicochemical parameters change over time (Maity, 2019; Das et al., 2022).

The species composition and spread of plankton are strongly affected by changes in physicochemical factors and the food supply. The results of this study show that physicochemical properties greatly affect how zooplankton are made up. Midya et al (2018) have found 41 different kinds of zooplankton in the Lentic estuarine ecosystems of Tajpur and New Digha (Bay of Bengal). There are two types of species: rotifers (12) and arthropods (29). No caducean species were found. There were five types of dominant species. *Calanus finmarchicans*, *Oncaea* sp., *Microsetella* sp., *Pseudodiaptomus hickmani* and *Acartiella* sp. So, a type of calanoid copepod is found in many estuarine wetlands. The most common species were both *Paracalanus* sp. and *Eucalanus crassus*.

The zooplankton species present at those sites have discontinuous distribution patterns that are strongly similar. Maity (2019) observed *Cyclops* sp., *Daphnia* sp., *Nauplius* stage, *Brachionus* sp., and other zooplankton species at the mouth of the Haldi River, where industrial effluents are discharged. *Cosmocalanus darwinii* is the most common species in the Bay of Bengal.

Table 1. Zooplankton's importance in aquatic biology.

Sl no	Feature	Function
1	Living fish food	Fish that feed on zooplankton have historically been regarded as major food sources.
2	Bio indicator	The best indication for determining the extent of water pollution, particularly nutrient-enriched eutrophication brought on by residential sewage pollution and pesticide toxicity, has also been determined to be zooplankton.
3	Mosquito population reduction	By preventing mosquito oviposition and larval development, they aid in the reduction of the mosquito larval population.
4	Trophic dynamics	Live-feed Zooplankton reduces the foraging energy required by their predators by making organic material available to higher trophic levels in a bigger pellet.
5	Larviculture and ornamental fish culture feed	Zooplankton is employed as a live food source in the culture of ornamental fish and freshwater larvae.

Types and shapes of MPs:

The three primary forms of plastic litter identified in prior studies were microplastic (5mm), and mesoplastic (5-25mm), and macroplastic (>25mm). Coastal areas, factories, and floodplains have all been found to contain microplastic, but the concentrations vary widely (Bhattacharyya et al., 2022). According to data collected thus far, the most common types of microplastics in the environment are polyethene (PE) and polypropylene (PP). Particles made of polyethene, polypropylene, and polystyrene are examples of microplastics frequently detected in cosmetic and pharmaceutical products (Horton et al., 2017). Plastics exposed to the air undergo photooxidation when exposed to ultraviolet (UV) radiation; as a result, they become brittle and break down into small pieces of plastic called microplastics. In aquatic environments, the process of plastic decomposing into smaller and smaller pieces occurs very slowly (Zhang, 2017). Depending on where they come from, microplastics can come in many different forms or morphologies, such as pellets, threads, or fragments. These forms are known as "morphologies" (Klein et al., 2015).

Botterell and his colleagues (2022) determined that the sizes of the MPs fragments present in the zooplankton samples ranged from '8 to 286 µm, with a mean size SE of 41±6 µm' in their study of MPs in zooplanktons. 75% of the MPs measured 'less than 50 µm' in length.

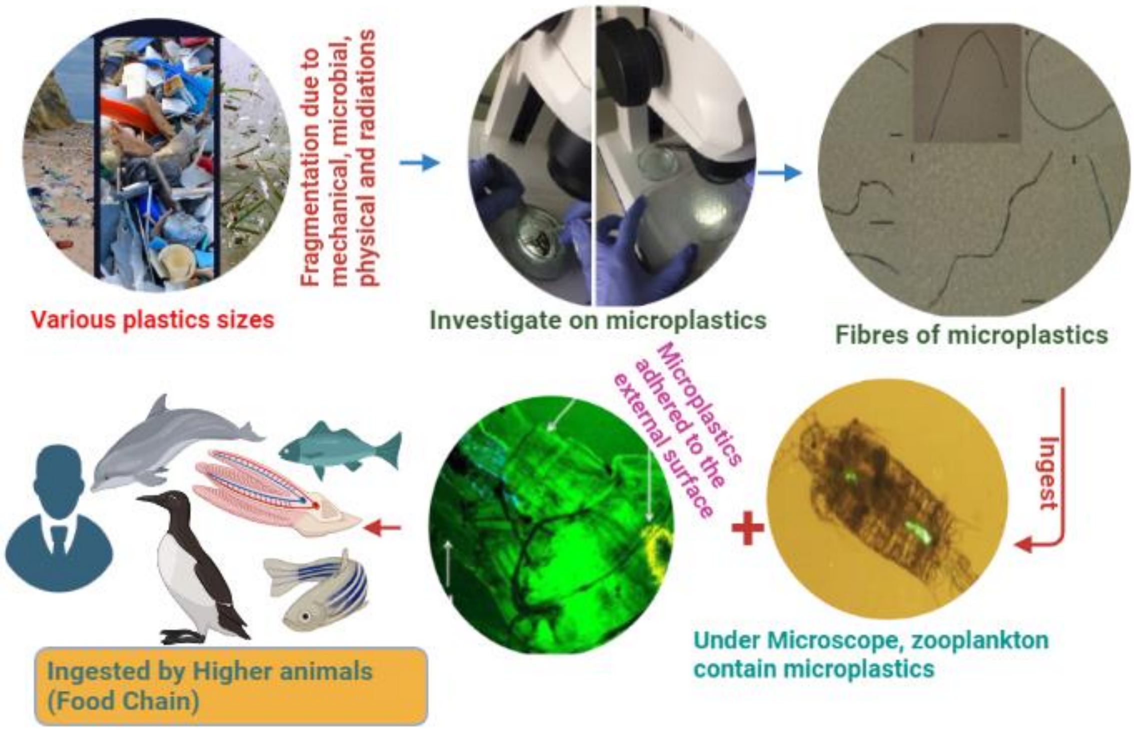

Figure 1. Plastic waste is reported in marine areas and on beaches. A microscopic image of microplastics (MPs) in various sizes. Fluorescence microscopy indicates that zooplankton can ingest different-sized MPs and may attach to their skeletons.

Microplastic influencing factors:

The natural environment has been contaminated by an excessive amount of waste made of plastic as a direct result of human activities and poor management. Plastic debris, once it has been released into the environment as a whole, is prone to fragmentation via UV degradation as well as physico-chemical and biological processes. This results in the debris finally breaking down into minute particles that are referred to as microplastics (MPs) (Thompson et al., 2004). According to Thompson et al. (2009), the abundance of microplastic that becomes accessible to a greater number of organisms will rise over time. This is because larger pieces of macroplastic will continue to degrade and break as time passes.

It has been predicted that the highest chance of encountering microplastics will occur in shelf-sea regions, whilst in other areas of high plastic occurrence, such as oceanic gyres, the likelihood will be relatively low due to low primary productivity and lower abundance of organisms (Clark et al., 2016). Several laboratory studies have shown that high abundance/concentrations of microplastics lead to increased ingestion (Kaposi et al., 2014; Cole and Galloway, 2015; Messinetti et al., 2017). In the field, Frias et al. (2014) found the microplastic abundance ranged from 0.01-0.32 cm3 m-3 and the zooplankton abundance ranged from 0.02-0.51 cm3 m-3 in coastal waters of Portugal.

Microplastics ingestion by zooplankton:

Microplastics are defined as fragments of plastic that are less than 5 millimetres in size and have become one of the most pervasive and widespread contaminants of marine ecosystems around the world. It has been extensively reported that marine biota, such as mussels, worms, fish, and seabirds, consume microplastics; nevertheless, despite their essential ecological function in marine food webs, the impact of microplastics on zooplankton has received insufficient attention.

Because of their comparable size, microplastics have the potential to be mistaken for a species' natural prey or to be passively absorbed during the course of regular feeding behaviour. It has been demonstrated that many species of zooplankton are capable of ingesting microplastics ranging in size from 0.5-816 µm (Cole et al., 2013; Lee et al., 2013; Cole and Galloway, 2015; Desforges et al., 2015). Cole et al. (2013) found that 13 out of 15 zooplankton introduced to beads made of polystyrene (7.3-30.6 µm) demonstrated the ability to consume MPs. They also observed live zooplankton and discovered that copepods, euphausids, and doliolids consumed MPs via filter-feeding. MPs were found on the external surfaces of zooplankton in both its living and preserved forms species such as 'copepods, decapod larvae, and euphausids. It was discovered that 13 zooplankton taxa, including 'holoplankton, meroplankton, and microzooplankton,' can consume polystyrene beads in the absence of natural food sources. According to Kvale et al. (2021), MPs are a nutrient-poor byproduct consumed by zooplankton alongside other food sources that primarily reduce primary producers' consumption of zooplankton and the nutrients associated with it. They demonstrated the possibility of an additional anthropogenic deoxygenation driver in which zooplankton ingestion of MPs reduces primary producers' grazing.

It is believed that the gape size of the mouthparts of the species is responsible for the size limitation of the microplastics that are eaten. Because smaller microplastics (15 µm) were consumed more frequently by the copepod *Calanus finmarchicus* than bigger microplastics (30 µm), this suggests that for this species, smaller microplastics had a better bioavailability (Vroom et al., 2017). Meroplankton were also found to exhibit size selectivity in their communities. According to Cole and Galloway's research (2015), Pacific oyster larvae of all ages were able to eat polystyrene beads ranging in size from 1.84 to 7.3 micrometres; however, only the larger larvae were able to ingest beads measuring 20.3 micrometres. According to the findings of Deforges et al. (2015), the *Euphausia pacifica*, the North Pacific krill, which is approximately 22 millimetres in length, preferentially ingests particles with a size of 56 micrometres, while the copepod, *Neocalanus cristatus*, which is roughly 8.5 millimetres in length, ingests particles that have an average size of 816 micrometres.

In the form of spherical beads, which are employed in cosmetics, and as fibres rinsed out from garments, microplastics can reach the environment directly through wastewater treatment plants (Thompson, 2015; Napper and Thompson, 2016). Because of the effects of weathering and deterioration on bigger plastics, microplastics can also take the form of pieces with an irregular shape.

On the other hand, microplastic spherical beads have been utilised almost exclusively in the context of laboratory-based research (Cole et al., 2013, Lee et al., 2013, Cole and Galloway, 2015). The fact that the microbeads were easily consumed by the majority of species is evidence that this particular shape is bioavailable to a diverse collection of taxa. A recent investigation conducted by Vroom et al. (2017) looked into the ingestion of microplastic pieces (less than 30 micrometres in size) in addition to microbeads. They discovered that both juvenile and adult *Calanus finmarchicus* were able to consume the fragments without any difficulty. In addition, Choi et al. (2018) discovered that sheepshead minnow (*Cyprinodon variegatus*) larvae were able to easily consume irregular polythene shapes that ranged in size from 6-350 μm.

According to Vroom et al. (2017), the natural ageing processes that occur in marine environments, such as weathering and biofouling, can cause changes in the physical and chemical properties of microplastics. According to Lambert et al. (2017), these processes will cause the degradation of microplastics, resulting in a reduction in their size as well as the creation of an irregular form and surface, which will ultimately result in an increase in their overall surface area. Adsorption causes the formation of a layer consisting of both organic and inorganic substances as soon as microplastics are released into the marine environment.

Effects of Microplastics on zooplankton:

The effects on feeding & life span:

According to Cole et al. (2013), microplastics can obstruct feeding appendages and restrict food intake. In an experiment with natural algae assemblages and polystyrene microbeads, copepods that consumed polystyrene microbeads significantly decreased their herbivory (Cole et al., 2013; Cole et al., 2015). Using a microplastic model, Cole et al. (2015) detected a significant shift in the size spectrum of algal prey consumed by copepods exposed to 20 μm microplastics. In response to the consumption of smaller prey items, there was a substantial reduction in the amount of carbon biomass consumed, resulting in a predicted loss of carbon of -9.1 ± 3.7 μg C copepod^{-1} day^{-1} (Cole et al., 2015; Botterell et al., 2019).

It is possible to experience an energy deficit if feeding behaviour or food intake decreases. This could negatively affect larval growth and development until adulthood. The copepod *Tigriopus japonicus* has been shown to extend its nauplius phase as a consequence of reduced feeding on algal prey caused by microplastic ingestion (Lee et al., 2013). Ingestion of polystyrene microbeads (2-5 m) by veligers of the marine gastropod Crepidula onyx not only leads to slower growth rates but also results in earlier development on the seabed at a smaller size, which might adversely impact post-settlement success. This research was conducted by Lo and Chan (2018).

Reduced eating, an insufficient supply of nutrients, or an obstructed or injured digestive tract are all potential causes of continuous loss of energy inputs, which can ultimately lead to mortality. Not only did the death rate of copepodites grow when chronically exposed to microplastics over the course of two generations in copepods, but the mortality rate of nauplii also increased (Lee et al., 2013). It's possible that this could have an impact on recruitment for subsequent generations, which would, in the end, lead to a smaller population size and, as a result, less food available for higher trophic levels.

Effects on reproduction process:

The process of reproduction requires a lot of energy, and if an animal does not get enough to eat, it could have an influence on their ability to reproduce. Several studies (White and Roman, 1992; Williams and Jones, 1999; Teixeira et al., 2010), among others, have demonstrated that a scarcity of food can lead to a decrease in the number of eggs that are laid by copepods. According to the findings of Lee et al. (2013), the fertility of *Tigriopus japonicas* copepods was significantly reduced after being exposed to repeated polystyrene microbead concentrations over the course of two generations. They also discovered that a significant number of egg sacs did not mature properly.

Biomagnification of MPs:

These previously contained MPs have the potential to be eroded by the wind and water. Then make their way into waterways and, ultimately, the estuarine aquatic environment. In addition, precipitation can potentially sweep MPs into drainage systems that have been produced due to tyre wear on roads (Kole et al., 2017). Plastic pellets, the forerunner of larger plastic products that are sometimes accidentally spilt during transportation, are yet another significant contributor to the problem of MPs pollution (Bandyopadhyay et al., 2023). Plastic pellets are also referred to as "nurdles" (Thompson, 2015).

MPs are anticipated to bioaccumulate in species at higher trophic levels by combining direct ingestion and trophic transfer. This is likely to be the primary mechanism. It is difficult to determine whether or not MPs have the ability to bioaccumulate in the food webs of marine mammals. The moderate to high microplastic bioaccumulation that has been projected in some lower trophic level marine species underscores the health dangers of toxic exposure to estuarine aquatic fauna that is heavily dependent on fish as well as coastal communities that are greatly dependent on seafood. This modelling work provides a technique to analyse microplastics' bioaccumulation potential and impact in the estuarine aquatic environment (Saha et al., 2022). This assessment aims to support risk assessment and inform plastic waste management (Alava, 2020).

It is possible that these MPs are consumed as a result of indiscriminate feeding behaviours, such as suspension feeding, in which prey are frequently consumed in a non-selective manner

(Cole et al., 2013). Previous studies have shown that certain species of zooplankton can adjust their diets to prioritise eating one type of algae over others and plastic beads (Ayukai, 1987). In addition to this, it has been discovered that the copepod, *Calanus helgolandicus*, when subjected to both MPs and algal prey, preferentially consumes algal prey of a smaller size (Cole et al., 2015). This change in feeding behaviour gives rise to the hypothesis that copepods are modifying their eating behaviour in order to avoid ingesting MPs.

Color-MPs and zooplankton relationships:

Due to their resemblance to prey items, the colour of MPs has the potential to boost their bioavailability. This is especially true for species that rely on their eyes for hunting (Wright et al 2013). However, the vast majority of tests have been conducted with pale-coloured microplastics, which numerous species of zooplankton readily consume (Cole et al., 2013; Cole et al., 2015). According to Desforges et al. (2015), the MPs fragments discovered inside a type of euphausiid and copepods were mostly black, blue, and red. MPs may be white or transparent also. On the other hand, there was no discernible difference in particle colour between the species. In a similar vein, Steer et al. (2017) discovered that the digestive systems of fish larvae contained mostly blue MPs (66%) and discovered that this matched the colour ratio of MPs in the surrounding environment, showing that there is no discrimination based on colour.

Discussion:

There is a wide variety of feeding behaviours that zooplankton are capable of displaying. These behaviours are determined by the life stage, species, and availability of prey. The majority of the zooplankton increase their chances of finding food by producing a feeding current that moves across the water. According to Phuong et al. (2016), microplastics that are present in an aquatic environment have the potential to be colonised by aquatic creatures and to absorb chemicals from their surroundings onto their surfaces. Over a period of a day, the consumption of algae by copepods was hampered by microplastics. This variable will have an effect on the zooplankton's ability to make use of the microplastics that are there. Ingestion has been explored as a pathway for the passage of microplastics between different trophic levels in a number of studies. On the other hand, there is a very limited amount of study being done on bioaccumulation of microplastics at the moment. In order to generate reliable risk assessments, it is essential to have a solid understanding of the potential consequences of microplastics across all levels of biological organisation. It is vital to have a better understanding of the harmful features that microplastics possess, both physically and chemically, at the cellular and organism levels in order to improve the information that is used for risk assessments. This, in conjunction with an additional study on how the presence of environmentally relevant microplastics and pollutants impacts complex activities such as motility, reproduction, prey selection, and eating behaviour, is essential to understanding the impact and risk to populations as well as the ecosystem. According to the findings of our review research, the form, size, and colour of microplastics might have a negative effect on the eating behaviour, reproduction, growth, development, and lifespan of zooplanktons. The fact that feeding rate, swimming speed, and reproduction are all altered at concentrations of MPs that are both environmentally relevant and unreasonably high in the laboratory suggests that these endpoints are sensitive and possibly have the ability to operate as a bioindicator to detect MPs levels in habitats. Daphnids survival rate, feeding rate, and fecundity were all dramatically reduced. It has been stated in a number of articles that when copepods were exposed to MPs, they experienced a reduction in both their feeding rate and their fertility. This may have a detrimental effect on copepod populations in the long term. The larvae of molluscs and barnacles, brine shrimp, and euphausids appear to be somewhat tolerant to MPs, which suggests that these species would be more dominant when confronted with extended MPs pollution. This is in contrast to daphnids and copepods, which appear to be very sensitive to MPs.

Future Research Prospects:

This review aimed to determine whether or not the most recent data was published to support the idea that microplastics (MPs), and bioaccumulate and biomagnify over a general marine food web, which is a notion that is frequently inferred in the literature on estuarine aquatic MPs contamination. There is a lack of data regarding microplastics' origin, distribution, and how they make their way into water. It is essential to do in-depth research on the aquatic biota since zooplankton are also at risk of exposure to potential toxins, and this risk can be passed on to higher trophic levels, reducing the overall level of food safety. Implementing circular economy principles can offer sustainable solutions to minimize plastic pollution, protecting the delicate balance of marine environments and supporting the resilience of zooplankton communities (Saha, 2023; Mukherjee et al., 2022; Rosenboom et al., 2022).

Conclusion:

This review focuses on the presence of MPs in zooplankton biota and the seasonal variation of those MPs in coastal estuaries. The majority of the researchers discovered that zooplankton population dynamics exhibited irregular fluctuation patterns. These patterns were attributed to the physical and chemical qualities of the body of water. There are a significant number of canals used for waste disposal in coastal estuarine regions. As a result, when a pollutant alters a significant portion of the water body, only a few zooplankton species become extremely dominant, and these plankton serve as an indicator of the specific water body. There is some evidence that zooplankton, an important component of the pelagic food web, might be used to transfer MPs to trophic levels higher up. This is yet another troubling finding from the review.

Conflict of interest:

The authors state that they do not have any competing interests.

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