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Review article

Plastics and their derivatives are impacting animal ecophysiology: A review

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The problem:

Nowadays, plastic pollution is posing a serious threat to marine biodiversity, ecosystem stability, and human health.

Millions of tons of plastic waste enter the oceans every year, and the impact of microplastics (MPs) is much more worrying than visible contamination.

Studies have shown that marine organisms, such as **corals**, **mollusks** and **fish**, not only ingest these particles, but also experience their toxic effects, which can result in metabolic alterations, inflammation and, in some cases, mortality.

This article aims to explore the various pathways through which MPs impact marine life, from ingestion and accumulation mechanisms to physiological responses of organisms.

ECOPHYSIOLOGY

ECOPHYSIOLOGY (or ecological physiology) analyze how physiological parameters reflect the interaction between an organism's internal environment and its external surroundings (Ferry-Graham and Gibb, 2008).

The term ecophysiology includes two related fields: ***functional morphology*** (animal's ability to move, acquire energy, and reproduce) and ***biomechanics*** (how the physical properties of an organism's tissues influence its survival and success) (Betz, 2006).

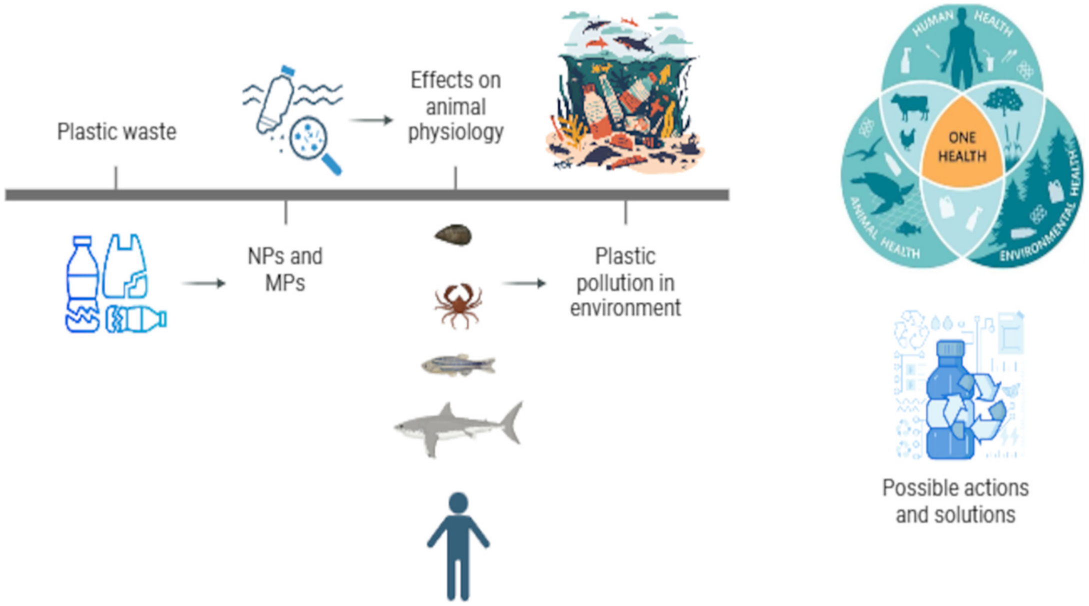
The role of ecophysiology is to investigate the limits imposed on organisms by their physiology, their responses to specific environmental challenges, and their adaptations to ecological niches. (Ferry-Graham and Gibb, 2008).

PLASTIC in the environment

According to the World Economic Forum 8 million tons of plastic waste enter the environment every year, while the Ocean Conservancy reports that there are currently 150 million tons (Gholamhosseini et al., 2023). [By 2030, 300 million tons!]

Plastic waste released into the environment is subject to continuous fragmentation into smaller particles. These can be classified into three distinct categories:

1. ***Macroplastics*** (> 5 mm in size);
2. ***Microplastics*** (MPs) (ranging from 0.1 µm to 5000 µm or 5 mm in size);
3. ***Nanoplastics*** (NPs) (1 nm to 100 nm in size) (Karbalaei et al., 2019).



During the COVID-19 pandemic:

Materials used in the manufacture of face masks include various plastic polymers such as polyethylene (PE), polycarbonate, polyester, polypropylene, polystyrene (PS), polyacrylonitrile, or polyurethane → significant impact on MP pollution, posing a serious threat to the environment and ecosystem.

PLASTIC vs. LIFE

Interaction between plastic waste and marine organisms can occur through two main pathways: ***direct physical contact*** and ***ingestion*** (Debnath et al., 2024).

Due to their size, MPs constitute optimal prey and are available for ingestion by various aquatic animals, including *zooplankton*, *mollusks*, *crustaceans*, *fish*, *seabirds*, and *marine mammals*.

Filter feeders, suspension feeders, and deposit feeders, which are particularly susceptible to ingesting suspended MPs, play a crucial role in linking different trophic levels and between pelagic and benthic ecosystems (trophic transfer of MPs).

How this affect animal ecophysiology?

MPs have harmful effects on marine organisms that result in a range of physiological responses and damage, and toxicity varies depending on the type, size and shape of the particles.

- MPs cause ***oxidative stress***, ***inflammation***, and ***metabolic disorders*** in marine animals (Banaee et al., 2024).
- MPs also adversely affect the ***reproductive capacity*** of marine organisms. Exposure to MPs in marine animals causes a variety of cellular responses at the cellular level.
- Furthermore, they cause a significant increase in the activity of phagocytes and mitochondria, up regulating oxyradical and immune cell levels (Gomiero et al., 2018).

Corals

MPs are commonly attached to *Pocillopora* spp. and *Acropora* spp. and can remain in the digestive system for at least 24 h, impacting trophic transfer, energy dynamics, and pollutant toxicity (Reichert et al., 2018).

The presence of MPs has led to health effects that include ***coral bleaching*** and ***tissue necrosis***.

These pollutants may accumulate toxins and opportunistic coral pathogens, such as *Vibrio* spp., inducing energy-intensive immune responses (Reichert et al., 2019).

The results of this study demonstrate that acute exposure to MPs instigates a stress response in *P. damicornis*, impairing detoxification and immune functions via the JNK and ERK pathways, thus weakening the coral's resilience to stress imposed by MP ingestion.

Mollusks

Most mollusks, which are marine, **sedentary**, burrowing, and **soft-bodied** animals, efficiently ingest MPs through filtration. This feeding strategy greatly increases exposure to MPs, making these organisms particularly vulnerable to them (Table 1).

In freshwater bivalves like *Corbicula fluminea*, the inhibition of cholinersterase enzyme activity and increased lipid peroxidation, due to the exposure to MPs, resulted in a reduced filtration rate (Oliveira et al., 2018).

In addition, a false sense of satiety, a common symptom in many aquatic species, was also reported. The molecular mechanism underlying this effect involves disruptions of the cholinergic and oxidative stress signalling pathways, both of which contribute to the reduction in filtration rate.

Table 1
Effects of MPs on bivalve species.

Type of polimer	Observed effects	Bivalve species	Substance concentration	Exposure time	Reference
PE	Uptake of MPs into gills, stomach and digestive gland; Inflammatory response; Destabilisation of lysosomal membrane.	Blue mussel (*Mytilus edulis*)	2.5 g HDPE-fluff/L	3 h–96 h	(Von Moos et al., 2012)
PE	Accumulation in gills and gut.	Freshwater mussel (*Anodontites trapesialis*)	0.3 g	3 h–92 h	(Moreschi et al., 2020)
PLA PE	Alterations in the structure of macrofaunal assemblages associated with oysters.	European flat oyster (*Ostrea edulis*)	0.8 μgL^{-1}; 80 μgL^{-1}	60 days	(Green, 2016)
PLA HDPE	Alterations in the structure of macrofaumal assemblages associated with oysters.	Peppery furrow shell (*Scrobicularia plana*)	0.8 μgL^{-1}; 80 μgL^{-1}	60 days	(Green, 2016)
PS	Higher diet intake; Decrease in oocytes, diameter and sperm velocity; Development of larvae decreased; Allocation of energy source to growth instead reproduction.	Pacific oyster (*Crassostrea gigas*)	0.023 mgL^{-1}	2 months	(Green, 2016)
PS PET PP PVC	DNA fragmentation in gills; Alteration of antioxidant enzyme activity in gills.	Mediterranean mussel (*Mytilus galloprovincialis*)	56 mgL^{-1}-180 mgL^{-1}	7 days	(Alnajar et al., 2021)
PS PVC	Accumulation of MPs in gills, stomach, intestine, gonad, mantle, adductor, foot; Inhibition of SOD activity.	Blue mussel (*Mytilus edulis*)	15 particles/individual/week; 1500 particles/individual/week; 15,000 particles/individual/week	42 weeks	(Hamm and Lenz, 2021)

Ostrea spp.

Mollusks

Simultaneously, exposure to microplastics induces oxidative stress, triggering the overproduction of **reactive oxygen species** (**ROS**).

Uncontrolled levels of ROS promote lipid peroxidation, causing membrane damage, particularly in gill and digestive tissues essential for filtration.

MP ingestion results in increased food consumption in oysters by compensating for the loss of energy in the digestive system. It also affects gametogenesis, gamete quality, and oyster fecundity, impairing reproduction. Researchers found that decreased oocyte size and quantity have a detrimental effect on recruitment because oocyte size and shape are positively connected with larval growth and survival. Moreover, reduced sperm velocity in male results in decreased fertilization rates and interferes with reproduction.

Crustaceans

The ingestion of polyethylene terephthalate (PET) microfibers has been observed to increase mortality of the freshwater crustacean ***Daphnia magna*** within 48 h (Jemec et al., 2016), as MPs can lead to potential blockages in the digestive tract.

The alterations of the feeding system of the pelagic copepod ***Calanus helgolandicus*** due to the ingestion of 20 μm PS-MPs causes a reduction in energy intake, as well as negative effects on reproduction due to a smaller egg size and reduced hatching success. Exposure to MPs results in much greater energy shortages in copepods than in non-exposed individuals.

Calanus helgolandicus

Daphnia magna

Crustaceans

Erioncheir sinensis

Oxidative stress caused by exposure to MPs can adversely affect the hepatopancreas, in which early inflammatory responses such as vacuolization, infiltration and necrosis were observed.

According to these results, exposure to MPs inhibited the growth of ***Erioncheir sinensis***, an effect that was most evident at the highest concentration of MPs.

The increase in GOT activity in crabs treated with a low concentration of MPs can be attributed to an immune reaction that favored the conversion between glutamate and oxaloacetate in liver cells. The reduced activity of the two aminotransferases indicates that MPs damaged the cells and the corresponding membrane organelles in the liver.

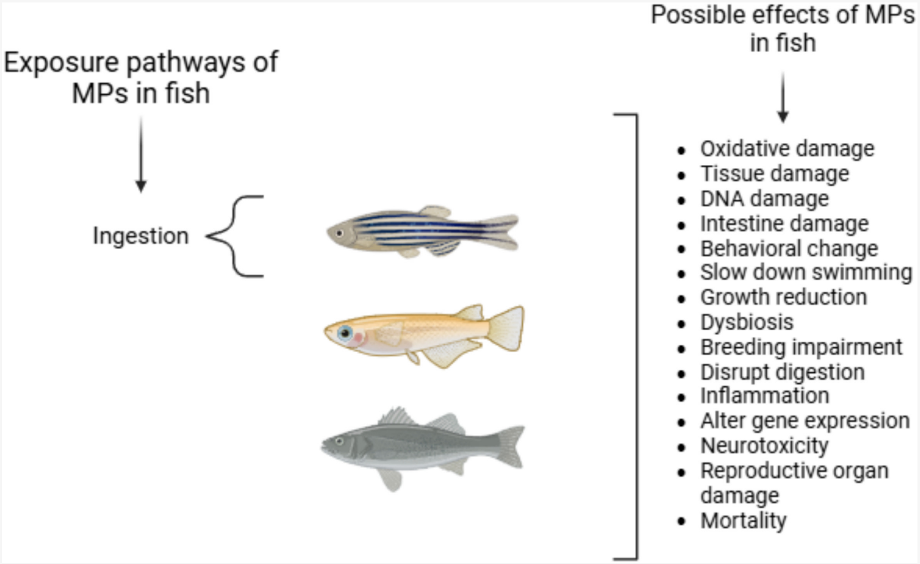
Consequently, an increase in cellular permeability occurred, which allowed the excretion of GPT and GOT from hepatopancreatic cells, causing a decrease in specific enzyme activity in the liver. Thus, exposure to MPs had a significant negative effect on the activity of antioxidant enzymes (Yu et al., 2018).

Fish

Inhibition of AChE activity can lead to a significant increase in acetylcholine levels in the brain interfering with the function of the nervous system. Furthermore, the accumulation of acetylcholine in the synaptic cleft results in over-stimulation of receptors, impedes neurotransmission and can even lead to paralysis and death → may explain the suppressed locomote ability observed in **zebrafish** groups exposed to NPs (Bhuyan, 2022).

MPs can also increase oxidative stress at the cellular level, leading to lipid peroxidation (LPO) by disrupting antioxidant defense systems. LPO occurs when ROS generated by exposure to MPs react with polyunsaturated fatty acids in the cell membrane, leading to the formation of lipid peroxides.

LPO can compromise the structural integrity and function of the cell membrane due to altered fluidity and permeability and has been shown to cause damage to muscles, liver, and gills in various fish species and other aquatic organisms.

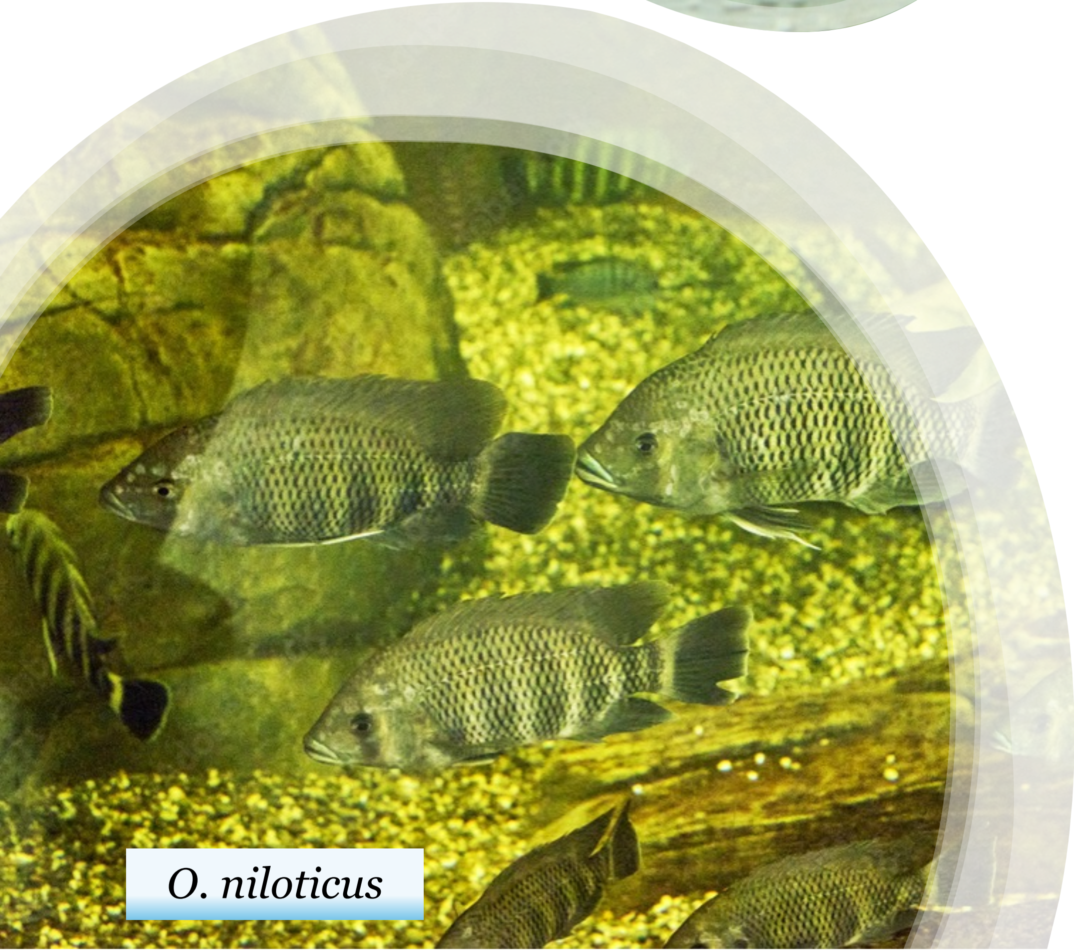


Fish

After exposure of ***Cyprinus carpio*** to 1 and 2 mg/L of PE-MPs for twenty-one days an increase in the activities of the enzymes creatine phosphokinase (CPK) and alkaline phosphatase (ALP) was observed (Impellitteri et al., 2022). In addition, there was a notable reduction in blood levels of total protein, globulin, albumin, triglycerides, and cholesterol, with a decrease in gamma-glutamyl transpeptidase (GGT) enzyme activity.

Similarly, exposure of ***Oreochromis niloticus*** to 1, 10, and 100 mg/L of MPs particles for 15 days showed a significant increase in blood levels of creatine, uric acid, and glucose, as well as altered functions of the aminotransferases aspartate aminotransferase (AST) and alanine aminotransferase (ALT) (Pothiraj et al., 2023).

Exposure to MPs results in the release of these enzymes from organs such as the heart, muscle, brain, kidney and liver into the circulation, increasing their levels. In addition, the observed changes in biochemical markers, including total protein, albumin, creatinine, triglycerides, globulin, glucose and cholesterol, are the cause of the physiological abnormalities found in fish exposed to MPs (Pothiraj et al., 2023).



MP and other pollutants

- MPs can absorb and interact with other environmental pollutants by acting as carriers in aquatic ecosystems (Pothiraj et al., 2023).
- MPs can absorb persistent, bioaccumulative, and toxic substances (PBT), such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), etc., which can desorb when ingested by aquatic species.
- MPs also accumulate metals from the water, which can be transported and subsequently ingested (Maršić-Lučić et al., 2018).

Possible solutions?

Standardized methods can be applied for the identification and quantification of plastic particles in water and biota.

In this regard, mussels have been proposed as sentinel species for large-scale monitoring programs (Li et al., 2019). To prevent environmental pollution, it is essential to conduct research into the recycling of plastic waste (Pothiraj et al., 2023).

Methods for the disposal of plastic products include landfilling, incineration, **recycling**, and **biodegradation** (Prasteen et al., 2018). Chemical methods such as hydrocracking, gasification, pyrolysis, chemolysis, and catalytic cracking are being studied as they may be able to convert plastic waste into valuable products (Pothiraj et al., 2023).

In addition, other strategies for reducing plastic pollution are the control of plastic sources through awareness programs and legislation, as well as the promotion of cleanup initiatives to remove plastics from the environment (Picó and Barceló, 2019).

Conclusions

In conclusion, plastic pollution represents an unprecedented environmental crisis, severely impacting animal ecophysiology and posing a serious threat to both life and human health.

MPs not only compromise marine ecosystems through direct ingestion mechanisms and interaction with toxic substances but also trigger processes of bioaccumulation and biomagnification along the food chain.

These particles accumulate in the tissues of organisms, causing physiological damages that undermine their vitality and disrupt trophic dynamics, with long-term consequences for biodiversity and the functionality of aquatic ecosystems.

Thanks for the attention!

LINK TO THE ARTICLE: https://www.sciencedirect.com/science/article/pii/S1532045625000304