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## Plastic Pollution's Effects on all Levels of Biological Function Present an Increasing Issue for One Health.

Aayushi Pal, Disha Sharma, Tanu Tyagi

Department of Biosciences, Shri Ram College, Muzaffarnagar

## ARTICLE INFO

## ABSTRACT

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## Corresponding Author

\*Aayushi Pal

The amount of plastic waste that has accumulated worldwide has reached crisis proportions. In order to integrate and better understand the intricacy of these processes, it is necessary to evaluate the various and multifaceted effects of plastic on biological health from a One Health perspective. Every ecosystem on Earth, from the highest mountains to the deepest oceanic trenches, contains plastic particles that range in size from nanometers to meters. All levels of biological organization—from the molecular and cellular to the organismal, community, and ecosystem levels—are impacted by plastic garbage. The chemical characteristics of the plastic polymers, the myriad of additives that are mixed with plastics during manufacture, the sorbed chemicals and bacteria that are carried by the plastic waste, and the physical characteristics of plastics all play a role in mediating these effects. We give a summary of the following themes using a One Health framework: 1) how plastic affects health worldwide at all levels of biological organization, 2) how plastic's effects interact with one another across biological layers, and 3) what information gaps exist about plastic's effects both inside and across biological scales. With a focus on One Health viewpoints that take into account the unity of humans, animals, and the environment, we also offer possible remedies to deal with this escalating catastrophe.

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## INTRODUCTION

Our civilization is full of plastics. Since the 1950s, the demand for plastic has increased dramatically because of its low cost, strength, durability, and light weight (Thompson et al., 2009). Soils (Fuller and Gautam, 2016), the open ocean (Eriksen et al., 2013; Cózar et al., 2014), the deep sea (Bergmann et al., 2017; Barrett et al., 2020), the atmosphere (González-Pleiter et al., 2021), and coastlines (Kwon et al., 2014; Courten-Jones et al., 2021) are all now affected by plastic pollution. According to current estimates, there are at least 5.25 trillion plastic particles in the world's oceans, and this quantity is only

projected to increase (Eriksen et al., 2014). Indeed, even if trash reduction measures are implemented immediately, it is estimated that the amount of plastic pollution entering the terrestrial and aquatic environment will increase by an additional 710 million metric tons between 2016 and 2040 (Lau et al., 2020). Bacterial activity, UV radiation, temperature, and abrasion are some of the biotic and abiotic environmental processes that break down these plastics into smaller pieces with different surface characteristics.

Because plastics are so prevalent in the ecosystem, interactions with humans and animals are now unavoidable. Plastics have an

impact on a large number of marine species (Gall and Thompson, 2015). Fish, clams, mussels, oysters, and crabs that are intended for human consumption contain microplastics (Van Cauwenberghe and Janssen, 2014; Li et al., 2015; Rochman et al., 2015; Karami et al., 2017; Su et al., 2018; Waite et al., 2018), as do table and sea salt (Yang et al., 2015; Zarus et al., 2021), seaweed (Baini et al., 2017), honey (Liebezeit and Liebezeit, 2013; Liebezeit and Liebezeit, 2015), tea (Hernandez et al., 2019), beer, and tap and bottled water (Kosuth et al., 2018; Zuccarello et al., 2019; Kankanige and Babel, 2020).

It's possible that no other single anthropogenic pollutant has been directly exposed to so many different layers of biology. By consuming plastic waste, plastics upset homeostasis at the individual organism level (Gall and Thompson, 2015). By destroying and altering habitats (Aloy et al., 2011; Carson et al., 2011; Richards and Beger, 2011) and disrupting the species balance across ecosystems (Barnes and Milner, 2005; Goldstein et al., 2012), plastic pollution can also interfere with ecosystem functioning. These alterations then unavoidably have unknowable health consequences. A strategy that goes beyond conventional species-level risk evaluations is needed to mitigate the negative effects of plastic on ecosystems, human health, and animal health.

In order to demonstrate the necessity of an integrated assessment, we highlight the effects of plastic pollution on various levels of biological organization by concentrating on exposure pathways and the health risks at the cellular, individual organismal, population, and ecosystem levels. This review's objectives are to: i) provide an overview of our current understanding of how plastic impacts biological organization layers; ii) make the case for using a One Health paradigm to comprehend and examine the health effects of plastic; and iii) highlight knowledge and research gaps regarding the effects of plastics within the One Health paradigm.

## ROUTES OF EXPOSURE

Humans and other species are exposed to plastics by ingestion, inhalation, and direct contact with plastics and plastic additive chemicals (Cox et al., 2020; World Health Organization, 2022). According to estimations, Americans consume between 39,000 and 52,000 microplastic particles annually from food and drink alone (Cox et al., 2020) or an average of 0.1 to 5g of microplastics per week (Senathirajah et al., 2021). It has also been demonstrated that other species eat plastic, including fish (Barboza et al., 2020), seabirds (Wilcox et al., 2015), turtles (Duncan et al., 2019), zooplankton (Desforges et al., 2015), and marine mammals (Nelms et al., 2019).

Plastics can be inhaled by humans and other terrestrial species in addition to being consumed. The washing of synthetic textiles, rubber tires, dried sludge, agriculture, and urban and domestic dust all contribute to the release of micro- and nanoplastics (MNPs) and plastic fibers into the atmosphere (Wright and Kelly, 2017; Karbalaei et al., 2018; World Health Organization, 2022). Even basic operations like opening and cutting plastic containers and packing can produce MNPs (Sobhani et al., 2020). Although the fate of inhaled MNPs and their subsequent uptake in lung tissue is currently unknown (Amato-Lourenço et al., 2021), airborne exposures can happen outdoors from particulate matter (Kasirajan and Ngouajio, 2012; Wright and Kelly, 2017; Catarino et al., 2018) as well as indoors through clothing and household items. Plastic additives, which are substances added to plastic to enhance the polymers' functionality, are inextricably linked to exposure to plastics (Hahladakis et al., 2018; Wiesinger et al., 2021). Plasticizers, flame retardants, heat and light stabilizers, pigments, lubricants, antistatic agents, slide agents, biocides, antioxidants, and thermal stabilizers are examples of additives (Groh et al., 2019). Although these compounds are useful for improving the performance of plastics, they

have the potential to contaminate food, water, air, and soil (Hahladakis et al., 2018), with unclear health and environmental effects.

Plastics can contain germs and contaminants from the environment in addition to the chemicals that are purposefully added. Numerous bacterial species, including human pathogens, have been linked to collected plastic trash, indicating that plastic may contribute to antibiotic resistance and the spread of infectious diseases (Rasool et al., 2021). Although additional research is required to determine whether these "Trojan horse" or "vector" effects of adsorption are physiologically significant, plastics are known to accumulate heavy metals and persistent organic pollutants (Thompson et al., 2009; Rochman et al., 2014). (Koelmans et al., 2016). When assessing the health effects of plastics, we need to take into account not only the polymers of plastics but also the possible exposure to a range of chemicals and microorganisms.

MNPs have the potential to adhere to the cell walls of algae (Nam et al., 2022), while also promoting lipid peroxidation, decreasing cell viability, altering the activity of antioxidant enzymes, and increasing the production of ROS (Das et al., 2022). Plastic's effects on organisms' development rates and energy requirements are connected to these biological alterations. For instance, although direct effects of plastics are not always obvious, nanoplastics may affect the metabolism and development rates of freshwater algae (Huang et al., 2019), chlorophyll-a concentrations (Zhang et al., 2018), and the maximal quantum yield of photosynthetic system II (Das et al., 2022).

Many invertebrates' growth, reproduction, and fitness are also impacted by MNP exposure. MNP exposure, for instance, has been shown to have an impact on mitochondrial gene expression, prey preference, lipid content, molting, feeding rates, filter feeding, survival, growth, and reproduction in copepods (e.g., *Calanus finmarchicus* (Cole et al., 2019),

*Daphnia magna* (An et al., 2021), and mussels [*Mytilus galloprovincialis* (Avio et al., 2015; Abidli et al., 2021)] (Wang et al., 2019). High-density polyethylene exposure caused lysosomal membrane damage, inflammatory responses, and the buildup of microplastics in the digestive gland of mussels (*Mytilus edulis*) (von Moos et al., 2012).

Few research have examined the effects of plastic exposure on the gut microbiome, despite the fact that the intestinal microbiota of vertebrates is essential to health and that disruption of the microbiota increases the risk of disease. In one study, male zebrafish exposed to polystyrene microplastics showed increased mucus levels and notable alterations in the species richness and variety of their microbiota (Jin et al., 2018). In a different study, the intestinal microbial population was altered in adult zebrafish (*Danio rerio*) that were co-exposed to titanium dioxide nanoparticles and the plasticizer bisphenol A (BPA) (Chen et al., 2018).

The immunological, antioxidant, neurological, and reproductive systems can all be disrupted by MNP exposure. For instance, mussels exposed to a combination of 2 and 6  $\mu\text{m}$  polystyrene microplastics showed changes in the activity or gene expression of antioxidant enzymes in their gills and digestive glands, disruption of cellular homeostasis in their hemocytes, and infiltration of these cells into tissues of the digestive system (Paul-Pont et al., 2016). *Cxcr5* and *Tnfrsf13b*, two proteins essential in B cell development, were upregulated in sheepshead minnows (*Cyprinodon variegatus*) exposed to irregularly shaped microplastics (Choi et al., 2018). According to other research, feeding fish microplastics with irregular shapes causes them to become more inflammatory (Jiang et al., 2016; Tao et al., 2016).

Fish behavior affected by MNP exposure at the nervous system level includes decreased locomotor activity (Chen et al., 2017); decreased predator avoidance behavior and dysregulated circadian rhythm locomotion

(Sarasamma *et al.*, 2020); increased shoal formation and feeding time and less exploration (Mattsson *et al.*, 2017); decreased predatory performance (Carlos de Sá *et al.*, 2015; Wen *et al.*, 2018); and decreased swim speed and erratic swimming (Barboza *et al.*, 2018). Polychaeteas and brine shrimp larvae exposed to nanoplastics have shown changes in their digging kinetics (Silva *et al.*, 2020) and locomotory behavior (Bergami *et al.*, 2016).

Lower micron ( $<5\ \mu\text{m}$ ) ingested MNPs have the ability to pass through the gastrointestinal barrier, enter the bloodstream, and maybe travel to other bodily parts (Roch *et al.*, 2020). The blood brain barrier (particles less than a few dozen  $\mu\text{m}$ ) and the egg chorion (typically particles smaller than a few hundred nm) are two other biological barriers that very small MNPs can get through (Guerrera *et al.*, 2021). Multicellular creatures are at more risk from this propensity for translocation across tissue barriers, since the plastic particles may have an impact on several physiological systems. Because many of these biological barriers are still developing, plastic can more easily spread to various organs during early developmental stages, making them especially vulnerable to this phenomenon.

The spread of plastics down the food chain and between generations is another cause for concern, especially with regard to fish and other marine life. MNPs have the ability to interact with zooplankton and phytoplankton, which small fish can eat and pass up the food chain (Benson *et al.*, 2022). Fish exposed to MNPs through their diet may have liver damage, slower growth, impaired swimming ability, and altered behavior (da Costa Araújo *et al.*, 2020; Kim *et al.*, 2022). Additionally, recent studies have shown that the translocation of plastics to fish gonads might cause physiological and developmental harm as well as the cross-generational transfer of these particles to the progeny (Pitt *et al.*, 2018b; Zhao *et al.*, 2021). These studies make it abundantly evident that

plastics have a significant impact on these keystone species' biology and fitness. Copepods, daphnids, and brine shrimp are examples of crustacean zooplankton that are important for community structure and serve as a vital link between primary producers and secondary consumers in the trophic chain. As major consumers at the base of the food chain, bivalves also provide habitat, contribute to the complexity and diversity of coastal ecosystems, serve as a vital source of nutrients for other species, and connect the benthic and pelagic systems through their filter-feeding activities. Fish are a major component of the ocean food web and a major source of food worldwide.

### **IMPACT OF PLASTICS ON PEOPLE**

Humans are clearly exposed to plastics and their metabolites on a regular basis, but it is currently unclear how these exposures affect human health. Exposure to plastics may cause respiratory irritation, dyspnea, decreased lung capacity, coughing, obesity, increased production of phlegm, cardiovascular disease, asthma, and cancer, according to research to date (Wright and Kelly, 2017; Karbalaee *et al.*, 2018; World Health Organization, 2022). Inflammation, immunological dysfunction, neurotoxicity, neoplasia, and metabolic alterations have also been suggested as potential effects of MNPs (Wang *et al.*, 2020; Banerjee and Shelper, 2021; Coffin *et al.*, 2022; World Health Organization, 2022).

The effects of BPA and phthalates have been the subject of a large portion of the research that has examined the health effects of plastics and plastic additives in humans. Development and reproduction are impacted by BPA and phthalates, which are known to disrupt hormones. While this can show up in women as an increased risk of endometriosis, reproductive-related cancers, and impaired ovarian function and menstrual cycling, it can show up in men as decreased reproductive capacity or an increased risk of testicular and prostate cancer (Meeker *et al.*, 2009; Kim and Kim, 2020). According to Basak *et al.* (2020),

exposure to endocrine disrupting chemicals during pregnancy may result in cancers and disorders of the kidney, prostate, testis, and immune system.

By altering the neuroendocrine system and inflammatory signaling, BPA and phthalates may also have neurological effects (Solleiro-Villavicencio *et al.*, 2020; Nadeem *et al.*, 2021). For instance, exposure to BPA has been connected to cognitive impairment, neurobehavioral problems, and neurodegenerative illness. BPA can also cross the blood-brain barrier (Wang *et al.*, 2019). Studies have shown a positive correlation between BPA and phthalates and cardiovascular disease, type 2 diabetes, and elevated blood pressure. Exposure to these chemicals is also linked to changes in the metabolism and cardiovascular system (Lang *et al.*, 2008; Gong *et al.*, 2013; Haq *et al.*, 2020; Mariana and Cairrao, 2020).

Although BPA and phthalates have been the subject of the great majority of studies on the health effects of plastics, more than 10,000 substances associated with the production of plastics have been identified in recent studies, including more than 2,400 substances that are classified as substances of potential concern (Hahladakis *et al.*, 2018; Groh *et al.*, 2019; Wiesinger *et al.*, 2021). There is obviously a lack of knowledge regarding the whole range of health dangers caused by plastics, as the current research has only examined a small portion of the compounds to which we are probably exposed on a regular basis. Clear exposures are found when these research go beyond a small number of substances.

Moreover, there is ongoing discussion on the possibility of plastic additives leaking out of plastic. With varying degrees of success, several studies have looked into the leachability of certain additives from things like plastic water bottles, kitchenware, and water pipes. According to some research, drinking water from plastic bottles and pipes has estrogenic activity (Wagner and Oehlmann, 2011; Liu *et al.*, 2017). However,

other studies have found that the amounts of leached additives are not high enough to be harmful to human health (Corea-Téllez *et al.*, 2008; Aneck-Hahn *et al.*, 2018; Wang *et al.*, 2019). These studies, however, do not account for the cumulative exposure that a person may experience over time and from many sources.

Given that exposure to plastic additives may persist even after removing plastics from one's surroundings, there is further evidence that the negative effects of plastic on human health are not easily reversed. For instance, even after BPA laws were put into place, BPA was found in 23 out of 29 urine samples taken from employees of a hazardous waste incinerator (González *et al.*, 2019). Furthermore, even after two months, an intervention research that eliminated all plastic sources from a family's home did not result in a discernible drop in phthalate metabolites in urine for any of the family members (Hutter *et al.*, 2016).

According to a recent World Health Organization report, research on MNPs' effects on health is urgently needed because it is currently "incomplete and insufficient for an assessment of human risk" (World Health Organization, 2022). It is evident that plastics have the potential to have a variety of negative effects on human health, even though research on these effects is sadly behind the consumption of plastic items. Chemical exposures from plastics can have systemic effects, ranging from cellular effects on oxidative stress and apoptosis to impacts on reproduction, development, metabolism, and even intergenerational effects through epigenetic modifications. The physical characteristics of plastics can also harm organs, including the respiratory and gastrointestinal systems.

#### **DIFFERENCES IN THE CAUSES AND EFFECTS OF EXPOSURE TO PLASTIC**

The effects of plastic pollution are not equally spread among communities, as is the case with many socioeconomic issues. High-income nations have accounted for 87% of all exports since the late 1980s, making them the main



exporters of plastic pollution (Brooks et al., 2018). High-income nations (the United States, Japan, Kuwait, Oman, Argentina, and Italy) account for six of the top 20 plastic polluters (Law et al., 2020). The majority of these exports go to Asiatic and Pacific nations with poorer incomes (Brooks et al., 2018). The disproportionate effects of plastic pollution in the nations that receive these exports are caused by the waste-management infrastructure in those countries being unable to handle the excess burden of the exports (Ncube et al., 2021).

The decline of the agriculture and fishing sectors, which are the main sources of income for some societies, is made worse by plastic pollution. About 10% of people on Earth, for instance, rely significantly on marine habitats for their food and livelihood; the majority of these people (95%) are from developing countries (Food and Agriculture Organization, 2014; Taylor et al., 2019). The plastic threat disproportionately affects low-lying Pacific islands with little arable land. To keep their economy and people afloat, Tuvalu, for example, adheres to "blue economy" strategies that depend on the usage of marine resources (International Organization for Migration and International Labour Organization, 2021).

### **ENVIRONMENTAL IMPACTS OF PLASTIC**

Human physical health, as well as societal, cultural, and economic well-being, are closely related to the health, function, and services provided by ecosystems (Summers et al., 2012). Sentinel species serve as examples of the diverse effects of plastic on all levels of biological organization, from cells to communities, and foretell a bleak future for the makeup of the natural world, including humans. They are effective indicators of detrimental effects on animal and human well-being at the individual and population levels because many marine apex predators, including marine mammals, have long lifespans, magnify trophic information across multiple spatiotemporal scales, and share food

resources that are important to humans for both subsistence and commerce (Bossart, 2011; Hazen et al., 2019).

Although there is a lack of research on whether plastic poses a threat to the functioning of entire ecosystems (Bucci et al., 2020), it is easy to envision the possible downstream effects of plastic on marine mammals and the ecosystems they live in, especially when viewed through the lens of population consequences of disturbance (Ocean Studies Board et al., 2017; Bucci et al., 2020). Ingestion or entanglement with macroplastics can cause physiological and behavioral alterations that have immediate or fatal effects on vital rates and, in turn, population dynamics (Ocean Studies Board et al., 2017). According to Ocean Studies Board et al. (2017), micro and macroplastics may potentially cause changes in vital rates and have long-lasting, non-fatal effects on personal health.

Naturally, a variety of factors affect how well an ecosystem functions, and the final ecosystem-level effects of disturbances brought on by plastic exposure may be influenced by processes such as emigration/immigration, prey-switching, changes in species assemblages, and niche partitioning, among others. In addition to plastic, ecosystems face numerous other anthropogenic stressors. Therefore, it is necessary to investigate the relationships between plastic exposure and climate change, habitat loss/degradation, exploitation, etc., and to protect ecosystems from plastic pollution in order to ensure the best possible health for humans, organisms, and the environment.

### **FUTURE RESEARCH INITIATIVES, MODIFICATIONS, AND SOLUTIONS.**

New technology advancements to break down or recycle plastic, consumer behavior campaigns, and the adoption of audacious laws at all governmental levels are just a few of the innovative solutions that will be required as long as human need for plastic persists. From lowering the quantity of new

plastic entering the environment to eliminating current plastic pollution, these solutions must be applied throughout the whole plastic lifespan. Numerous plastic capture techniques are among the technological advancements being used in cleanup and remediation operations.

The use of microbes that break down plastic as a means of establishing a "circular economy of plastic" is another innovative strategy to stop plastic pollution. Over the past century, microbes have developed enzymes that break down plastic due to its increased presence in the environment [reviewed in Sheth *et al.*, 2019]. Although hundreds of bacterial strains may have developed plastic-degrading capabilities, none have been able to do so quickly. Nevertheless, as these naturally occurring enzymes have been further refined, microbially-mediated plastic bioremediation systems have become more effective (Tournier *et al.*, 2020; Lu *et al.*, 2022). Along with these significant advancements in bacterially-mediated plastic degradation, it will be crucial to convert plastic waste into forms that are completely and easily biodegradable, like amorphization or micronization.

Governments everywhere are utilizing policies, laws, and ordinances to address the problem of plastic pollution at the same time that new solutions are being developed. By utilizing economic, educational, and regulatory tools, policies can address plastic pollution in a number of ways. According to a recent analysis of plastic policies worldwide, national and subnational policies most commonly employ plastic bans to reduce plastic pollution, but international policies mostly concentrate on plans and future actions (Diana *et al.*, 2022). There are still significant gaps in the policy arena, especially the kinds of plastic that these rules target, despite this growing trend.

A planetary boundaries strategy has been put out to help direct international policy efforts by first defining the waste production limitations that guarantee Earth's continued

status as a "safe operating space" for humanity (Folke *et al.*, 2021). As of right now, planetary boundaries have been established for the following: ocean acidification, freshwater consumption, genetic diversity, land-system change, climatic change, biochemical fluxes (phosphorus and nitrogen), and the loss of stratospheric ozone (Steffen *et al.*, 2015). Experts haven't yet established planetary bounds for plastics or other new substances, though. Society can determine whether plastic pollution is causing extensive and irreparable damage to the world and devise preventative actions by quantifying the planetary boundary for plastic contamination.

Lastly, more research on the effects of plastic is required in addition to better technology and laws to combat plastic pollution. Numerous significant research gaps have been identified by a recent assessment of papers looking at the effects of plastic pollution (Bucci *et al.*, 2020). Microplastics have been the main focus of manipulative laboratory studies 96% of the time, whereas macroplastics have been the main focus of observational or manipulative field experiments 97% of the time. Only a small number of studies examined other polymer kinds, such as PVC, PET, polypropylene, and others; most of the tests that examined microplastics employed polyethylene and polystyrene. Last but not least, freshwater and terrestrial ecosystems have received comparatively little attention, with 76% of all studies concentrating solely on the marine environment.

## CONCLUSIONS

There is growing evidence that plastic can affect many levels of biological organization, ranging from organismal and population levels to molecular and cellular levels. These effects are extensive, causing changes in the microbiome, behavior, reproduction and development, neurologic function, metabolic function, inflammation, and oxidative stress. The physical affects of swallowed or absorbed plastic particles as well as the chemicals and

bacteria found in or on the plastics mediate these effects.

There are still numerous unanswered questions regarding the effects of plastics on the health of people, animals, plants, and ecosystems as a whole, despite the increasing amount of study on the subject. In order to account for the extensive variations in polymer type, plastic particle size, and additive mixes, more thorough and methodical research is required. Furthermore, little is known about the cumulative exposure to plastics and additives over time across different levels of biology, and there is a noticeable dearth of research that integrates the effects of plastic pollution at the cell, organismal, population, and ecosystem levels. Furthermore, the rate of plastic production and consumption is significantly outpacing the pace of global policy reaction and the deployment of technology that reduce plastic.

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