The Research of Medical Science Review

Received: 18 October, 2024
Accepted: 18 November, 2024
Published: 25 November, 2024

ISSN: 3007-1208 | 3007-1216
Volume 2, Issue 3, 2024

MARINE PLASTIC POLLUTION: IMPACTS ON AQUATIC FAUNA AND ECOSYSTEM HEALTH

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ABSTRACT

Aquatic species and ecosystem health are significantly impacted by marine plastic waste, which has become a global environmental emergency. This analysis highlights the wide distribution of plastic pollution from coastal seas to the deep sea by examining its sources, kinds, and transport mechanisms. Physical harm from eating and entanglement, toxicological consequences from chemical leaching and pollutant absorption, and disturbances in behavior and reproduction are some of the main effects on marine creatures. Plastic waste changes habitats upends food webs, and affects the dynamics of microbial communities by forming plastispheres at the ecosystem level. The efficacy and limitations of current mitigation strategies, including source reduction, cleanup campaigns, and legislative actions, are assessed. The assessment also points out areas that require more investigation, especially to comprehend the long-term ecological effects and develop sustainable substitutes for traditional plastics. This study emphasizes how urgently international cooperation is required to combat marine plastic pollution to protect biodiversity and preserve ecosystem integrity.

Keywords: *Marine plastic pollution, Plastic ingestion, Aquatic wildlife impacts, Ecosystem health*

INTRODUCTION

The Marine and coastal environment is a highly productive zone consisting of different subsystems, such as coral reefs and seagrasses. It is a complex environment with rich biodiversity ranging from various primitive (horseshoe crabs) to advanced organisms (dolphins). The marine environment is the vast body of water that covers 71 percent of the earth's coverage. However, the global ocean system is divided into five major oceans and many seas based on historical, cultural, geographical, and scientific characteristics, and size variations. Five ocean basins, i.e., Atlantic, Pacific, Indian, Arctic, and Antarctic, are the most known marine systems invaded by humans. The accumulated plastics in the ocean basins can be broadly classified into four levels based on their sizes: megaplastics, macroplastics, mesoplastics, and microplastics. Microplastics are found in commonly manufactured, commercial products such as personal care and cosmetic products or microplastic particles produced from in-situ environmental degradation and subsequent fragmentation of larger size plastics by physical, chemical, and biological processes [1]. Microplastics are mostly abundant in marine and coastal systems, while synthetic pollutants chemically interact with organic pollutants and metals [2]. The density of microplastics also affects the distribution of microplastics in the water column. Polypropylene (PP) and polyethylene (PE) float in water due to the low density of plastics, while polystyrene (PS), polyvinyl chloride (PVC), polyamide (PA), and polyethylene terephthalate (PET) with higher density do not float in water, but deposit by inclination through the water column. Accordingly, coastal and marine systems widely distribute microplastic pollutants in every sub-zone/layer (pelagic and benthic). Salinity is one of the key factors affecting the chemical degradation of plastic. Hence, coastal and marine systems, which range at approximately 0.5–35/00 (ppt: parts per thousand) of salinity, are highly susceptible to the formation of microplastics. Accordingly, scientific evidence of the distribution and persistence of microplastic pollutants must focus on ocean basins and coastal ecosystems to identify the nature of the emerging issue [3].

Potential Effects of (Micro) Plastics on Marine Ecosystems

The impacts of plastics on marine ecosystems range from direct health effects in marine organisms, due to ingestion or entanglement in litter and fishing gear, to hitchhiking (i.e., attaching to and floating with plastics) of organisms, including invasive species and pathogens, to impacts on fisheries (including damaged gear, decreased catches), to loss of ecosystem services (GESAMP 2015). Research on microplastics indicates that ingestion of microplastics by marine organisms can cause a range of effects, including blockage of intestinal tracts, inflammation, oxidative stress, hormone disruption, reproductive impact, and metabolic and behavioral changes [4]. However, recent research finds that exposure to smaller, nanoplastic3 particles is more likely to cause adverse outcomes [5]. The impacts of micro- and nanoplastics on marine environments at the ecosystem level are largely unexplored but may include changes in nutrient cycles and food chains as well as changes in microbial communities growing on plastics [6]. Although some research has indicated that microplastics may cause several effects, current research is dominated by two opposing views: microplastics have clear impacts on marine ecosystems [7], and the current risks associated with microplastics have thus far not been proven to exist [8]. However, many frequently used chemical additives in plastic products have been found in marine ecosystems [9]and these chemicals cause endocrine disruption, developmental disorders, and reproductive abnormalities in a wide range of vertebrate species (including fish and marine mammals) [10]. The sources of these chemicals in marine environments may be linked to leachates from plastic debris (i.e., chemicals such as flame retardants, phthalates, and phenols may leak out of plastic objects into marine3Nanoplastics are particles that range in size from 1 to 1000 nm, or 10^{-9} to 10^{-6} m. For comparison, a strand of human DNA is 2.5 nm in diameter and a human hair is approximately 80,000–100,000 nm wide. Marine Plastic Pollution: Sources, Impacts, and Policy Issues 319waters) or diffuse sources (e.g., wastewater, sewage, atmospheric deposition), which result from the pervasive use of plastics and chemicals worldwide [11].This review aims to thoroughly investigate the widespread problem of marine plastic pollution, emphasizing the kinds, sources, and modes of transportation of this material in aquatic habitats. In addition to the more general ecological repercussions on ecosystems, food webs, and microbial communities, it seeks to examine the complex effects on marine life, including behavioral, toxicological, and physical implications. Along with identifying research gaps and suggesting future options for tackling this pressing environmental issue, the review also aims to assess current mitigation techniques, such as prevention, cleanup initiatives, and legislative interventions.

Marine plastic pollution: Sources, Pathways and Estimation

Notwithstanding these studies, the global research agenda on marine plastic pollution gained momentum after the first two conferences organized by the US National Marine Fisheries Service in Honolulu between 1982 and 1984 [12]. The prevalence of litter in the open oceans is highlighted by numerous images of plastic showing on shorelines and flowing into rivers before entering the oceans and by the fact that every year large quantities of litter are collected by ocean cleanups around the world. For instance, the 2017 cleanup event showed that the dominant top items collected around the globe based on item counts of coastal litter were all made of plastics, which was repeated during the 2018 cleanup event [13]. Meanwhile, some studies provide estimates of marine plastic debris. As recently reported by Eriksen et al.[14], an estimated figure of the volume of plastics floating in the oceans, and found that more than five trillion pieces of plastic and approximately 268,940 tons are currently floating in the oceans. The estimation however excluded plastic litter on the seafloor. The widespread use of single-use plastic and unmanaged disposal of litter along with poor waste management and recycling practices contribute to the growing accumulation of litter in the oceans. In terms of transportation pathways, leakages from municipal solid waste streams which ultimately end up in the seas have been viewed as an increasing source of plastic debris in the oceans [15]. Results from studies estimating MPP–covering both ocean and land-based sources–indicate these are very large [16]. The total plastic pollution of 15 million metric tons per year is estimated. These estimates were based on compilation from previously published sources. The marine environment has become a substantial reservoir for plastic litter with huge negative effects [17]. The definition of marine plastic debris deepened necessitating studies on other sources and forms of marine debris [18]. A new perspective to this debate found microplastic in Arctic polar waters and suggests that the accumulation of plastic can be attributed to transporting agents such as ocean currents, winds, and tides. These agents enhance the transport of plastic to remote regions far from the sources. Inland populations contribute between 0.79–1.52 million tons per year of plastic to oceans through river transport [19]. Their findings were based on plastic inputs from inland areas (>50 km from the coastline) to oceans. By analyzing the distribution and abundance, plastic litter can be found in marine ecosystems, including beaches, shorelines, surface waters, and on the seafloor [20].

Different types of plastics

The main types of plastics that are manufactured2 are resins, i.e. polyethylene (116 Mt), polypropylene (68 Mt), polyvinyl chloride (38 Mt), polyethylene terephthalate (33 Mt), polyurethane (27 Mt), and polystyrene (25 Mt), along with 59 Mt of (polyester, polyamide, and acrylic) fibers, plus 25 Mt of ‘additives’. Very many commonly used items are made from various types of plastics, for example, those shown in Figures 1 and 2. The golf ball, shown in Figure 3, is an example of an object made from a combination of different plastics, consisting of a polybutadiene rubber core, surrounded by a hard ionomer resin shell. Some other representative examples of plastics in common use are given in the following list. • Polyamides (PA) (including nylon): fibers, bristles for toothbrushes, tubing, fishing line, and low-strength components, for example, engine parts or gun frames. Polycarbonate (PC): compact discs, eyeglasses, riot shields, security windows, traffic lights, ‘plastic’ lenses, and smartphone unibody shells (Figure 1). • Polyester (PES): fibers and textiles. • Polyethylene (PE): used to make cheap packaging and wrapping materials, along with disposable supermarket shopping bags, and plastic bottles. • High-density polyethylene (HDPE): detergent bottles, milk jugs, and molded plastic cases, to contain various items. • Low-density polyethylene (LDPE): garden furniture, floor tiles, shower curtains, and clamshell packaging. • Polyethylene terephthalate (PET): bottles to hold carbonated drinks, food jars, plastic films, and microwavable packaging. • Polypropylene (PP): bottle caps, drinking straws, yogurt containers, household appliances, tables and chairs, car bumpers (fenders), and pipe systems designed to withstand pressure. • Polystyrene (PS): loose foam packaging, food containers, plastic tableware, disposable cups, plates and cutlery, and boxes for compact discs and cassettes. • High impact polystyrene (HIPS): refrigerator liners, food packaging, and vending cups for drinks. • Polyurethanes (PU): foams for cushioning, foams to provide thermal insulation, surface coatings, rollers for printing, and is the most common plastic currently used in cars. • Polyvinyl chloride (PVC): pipes for plumbing and guttering, doors, and frames for doors and windows, flooring material, shower curtains. • Polyvinylidene chloride (PVDC): food packaging film, such as Saran. • Polybutadiene: car tires, to increase the impact resistance (toughness) of plastics such as polystyrene and acrylonitrile butadiene styrene (ABS), and to make golf balls (Figure 5). • Acrylonitrile butadiene styrene (ABS): computer monitors, printers and keyboards, drainpipes. • Polycarbonate/acrylonitrile butadiene styrene (PC/ABS) blend a stronger plastic used to make the interior and exterior parts of cars, and the unibody shells of mobile phones. • Polyethylene/acrylonitrile butadiene styrene (PE/ABS) blend a low-friction (slippery) material which is used in low-duty, dry bearings.

Figure 1: A variety of household objects made out of plastic.

From top left to bottom right: measuring cup, tape dispenser with tape, cooking timer, plastic jug, pill container, medical inhaler pump, plastic fold-top sandwich bag, crocodile clip, CD. Credit: ImGz, https://upload.wikimedia.org/wikipedia/commons/b/b2/Plastic_ household_items.jpg [21].

Figure 2: Smartphone with a polycarbonate unibody shell and Golf ball, consisting of a polybutadiene rubber core, surrounded by a hard, polyethylene ionomer resin shell [21].

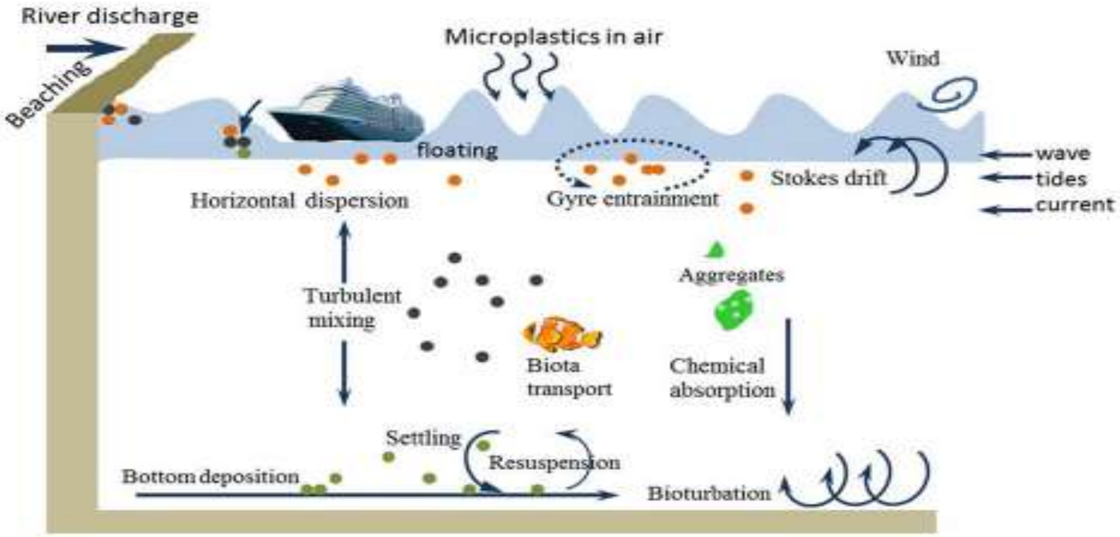
Microplastic and macroplastic:

Debris is generally assessed according to size: macro plastics, i.e. plastic items superior to 5 mm, and microplastics, i.e. plastic items inferior to 5 mm [22]. More precisely, micro plastics can be classified as (i) primary micro plastics that are specifically engineered to be used in this form, mainly in cosmetic products or as preproduction pellets, and (ii) secondary microplastics that come from the degradation of larger plastic items mainly due to photo-degradation or mechanical action [23]. In the continental aquatic environment, micro-plastic assessment is conducted to estimate contamination of the environment and the influence of anthropogenic activities (e.g., and also to evaluate microplastic ingestion and impact on organisms [24]. With regards to macroplastic, it is widely considered that around 80% of marine debris is from land-based sources even though a recent study estimated that 30% of coastal plastic debris comes from marine activities and 47% corresponds to unidentifiable fragments. Therefore, the macroplastic assessments from in situ sampling aim to both quantify the floating debris [25] and estimate the riverine plastic fluxes or plastic exported to oceans [26]. The mass estimate of continental plastic waste entering the ocean can also be calculated using a statistical approach based on governmental databases as exposed by [27].

Mechanisms of Plastic Pollution in Aquatic Environments

Marine microplastics have a wide distribution in the world. In coastal regions, landbased sources are considered to be a major contributor to marine plastic debris [28]. For coastal areas, plastics can be directly released to the ocean by mismanaged dumping, or from shipping and recreational activities. Lebreton et al. (2017) estimated that between 1.15 and 2.41 million metric tonnes of plastic waste enters the ocean every year from rivers. Schmidt et al. (2017) revealed that rivers are a major pathway for plastic transport into the sea, which contributes between 80% and 94% of the total plastic load. The nearshore plastic concentrations have a strong correlation with the coastal population [29]. The highest abundance of microplastic debris has been observed through numerous field surveys in rivers, harbor areas, tourist beaches, as well as nearby industrial areas [29]. Simulating the transport of microplastics is challenging because the transportation includes physical, chemical, and biological processes. Moreover, the physical properties (e.g., size, shape, density, buoyancy) of microplastics, which vary considerably, influence their transport. The transport process of floating plastics in the ocean is primarily determined by dynamic conditions, such as wind forcing and geostrophic circulation. The circulation pattern results in surface accumulation zones that are characterized by convergent particle paths, including plastic debris in subtropical gyres [30]. A subtler influence on the distribution of floating microplastics is that of the wind. Besides wind-driven currents, wind waves induced Stokes drift, which can be locally responsible for microplastic transport in shallow coastal waters because of nonlinearity. Onshore transport of drifting microplastics in coastal waters is caused by a combination of surface residual currents, wind, and Stokes drift [31]. Iwasaki et al. (2017) used a wave model to calculate the Stokes drift and found that the transit time was drastically reduced by considering such drift. These results indicate that Stokes drift plays an important role in coastal microplastic transport.

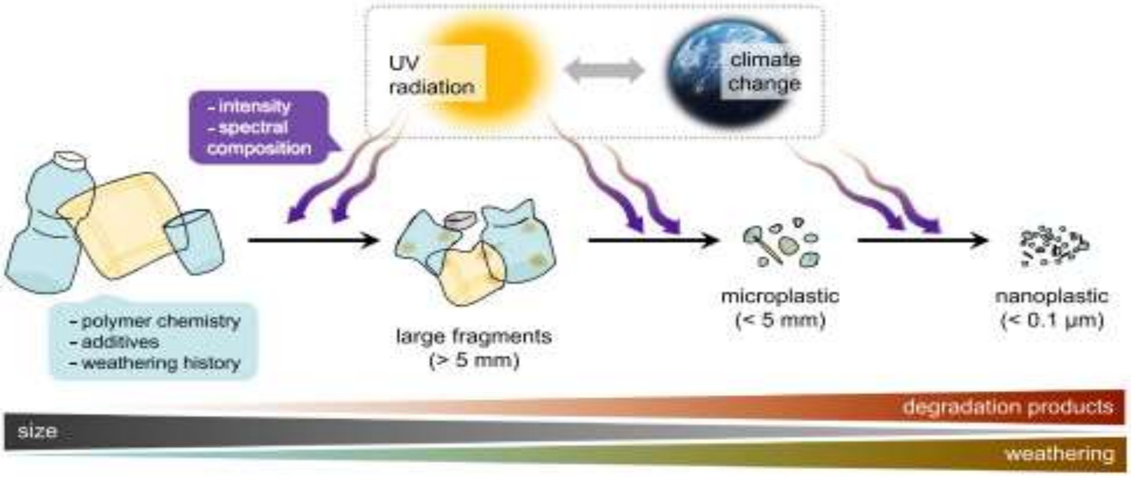
Figure 3: Schematic of the transport pathways of microplastics in the ocean (modified from Welden and Lusher 2017 [32].



UV radiation-driven photo-oxidation and formation of microplastics

Pathways of UV-induced transformation of plastics have been identified [33].Direct exposure of plastics to solar UV-B radiation induces free-radical photoreactions resulting in the photo-oxidation of the plastic (Fig. 1). Exposure of a photosensitizer (e.g. dissolved organic matter (DOM)) can also result in the degradation of some plastics via the production of hydroxyl radicals and other reactive oxygen species [34]. The consequent deterioration of physical properties, surface erosion, and discoloration, are referred to as weathering. Exposure to UV radiation renders common plastics such as polyethylene (PE) and polypropylene (PP)] weak and brittle. This makes them more susceptible to fragmentation under environmental mechanical stresses [35]. which leads to the release of microplastics and nanoplastics into the environment (Fig. 4). Some fragmentation can also occur due to mechanical forces alone, for instance, during agricultural processes (Sect. 4.2) and in the marine environment [36]. To counter weathering and the deterioration of mechanical properties, the practice of adding UV-protective substances to plastics is widespread, prolonging the useful lifetimes of plastic products used outdoors [37]

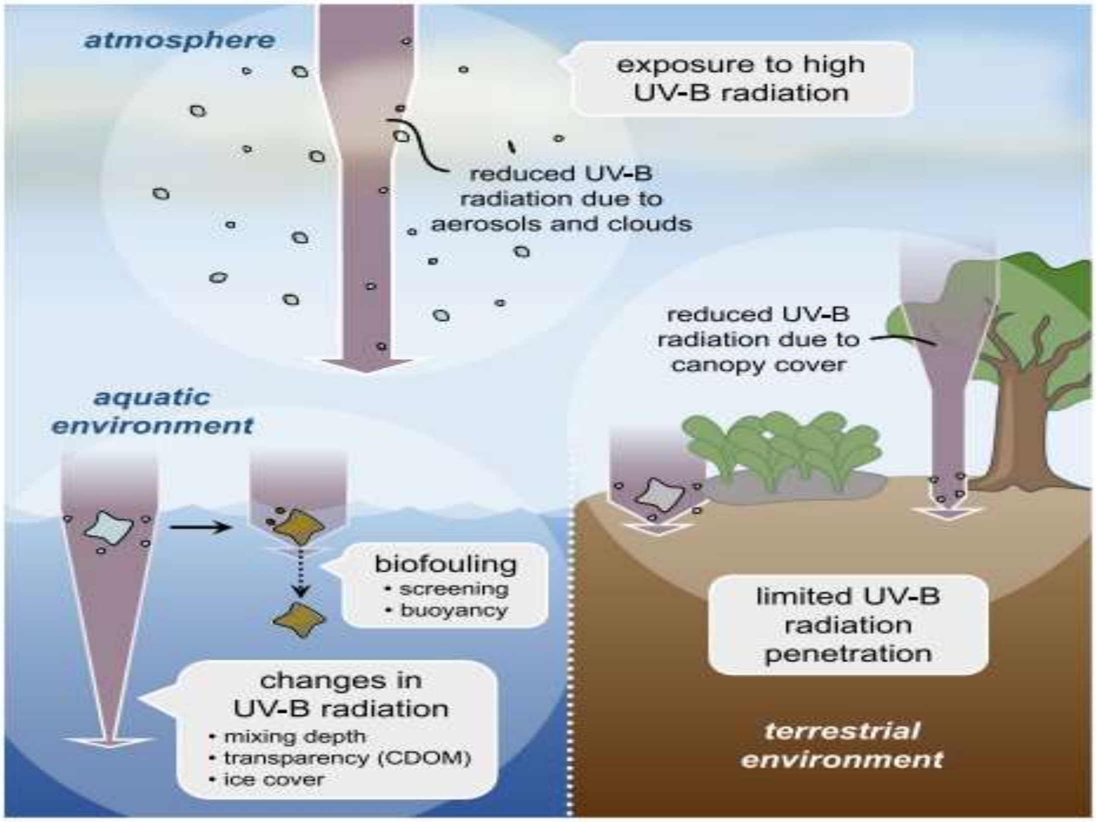
Figure 4: Conceptual diagram depicting the formation of micro- and nanoplastics under natural conditions.



UV radiation and mechanical stress (not shown) drive the weathering and fragmentation of larger plastic waste into smaller fragments and other by-products (e.g. CO2, CH4, and leachates; not shown in the figure) [38].

Degradation of plastics occurs through two basic mechanisms: (1) photo-oxidation followed by fragmentation and release of dissolved organic matter (DOM); and (2) mineralization. Mineralization refers to the final step in the degradation process where the plastics are decomposed, usually oxidatively, into inorganic end-products such as water and carbon dioxide. Fragmentation, DOM release, and mineralization processes occur concurrently in the dark, but rates are enhanced, albeit to a variable extent, in plastics exposed to solar UV radiation [39]. Solar UV-facilitated oxidation, and subsequent fragmentation, produce large numbers of nanoscale or very small microscale plastic fragments [40]. However, leaching of DOM from solar UV-exposed plastics under outdoor conditions has been reported, indicating at least the partial conversion of a fraction of the plastics into water-soluble organic compounds [89]. Nevertheless, even under accelerated exposure the process is slow, and it might be speculated to be even slower in natural environments.

Figure 4: Effects of UV(-B) radiation on plastic litter in various environmental compartments.



In the atmosphere, micro- and nanoplastics are exposed to high levels of UV-B radiation; only aerosols and clouds provide a partial UV screen. In aquatic environments, UV-B radiation penetrates only to a limited extent into the water column, leading to a gradient of UV-B varying from high exposure at the water surface to virtually zero exposure deeper in the water column and within sediments [38].

Effects of Plastics on Marine Biodiversity

The magnitude of plastic pollution carried to sea has significantly multiplied over the past several decades. Oftentimes, wildlife is injured due to entanglement or ingestion of the plastics found in the environment. For Procellariiformes such as albatrosses, shearwaters, or petrels, the appearance of eroded plastic pieces is similar to the many types of food they consume [41]. Microplastics resemble phytoplankton which are eaten by fish and cetaceans [42]. Ingested plastic debris has been found to reduce stomach capacity, hinder growth, cause internal injuries, and create intestinal blockage. Plastic entanglement with fishing nets or other ring-shaped materials can result in strangulation, reduction of feeding efficiency, and in some cases drowning [43]. Due to natural curiosity, pinnipeds often become entangled in marine debris at a young age, which can constrict their body as they grow thus reducing quality of life. Globally, at least 23 % of marine mammal species, 36 % of seabird species, and 86 % of sea turtle species are known to be affected by plastic debris [44].

Sea Turtles:

Numerous autopsies have shown that ingested plastic and tar are the primary culprits of stress and non-natural death for sea turtles. Debris including fishing lines, ropes, nets, six-pack rings, Styrofoam, and plastic bags have been extracted from turtle digestive tracts. Plastic bags floating in the water strongly resemble the shape of jellyfish, a primary food source for sea turtles, thus resulting in the ingestion of the bags [45]. Due to anthropogenic impact, the population of leatherback sea turtles (Dermochelys coriacea) has steadily declined over the last two decades, placing them on the IUCN's critically endangered list [46]. For the last 40 years, of the 371 autopsies conducted on leatherback turtles, 37.2 % of them had plastic in their gastrointestinal tracts [47]. Although it is not known if the plastic ingested was the cause of death, 8.7 % of the turtles had a plastic bag presumably blocking the passage of food. Plastic has also been found to block the passage of female eggs. In a documented study, researchers removed 14 pieces of plastic from a female cloaca. This enabled the eggs to be laid, but an indication of internal damage remains [48].

Birds:

Small plastics such as bottle caps are often mistaken by seabirds (Procellariiformes) for food. In several studies, it was found that diving birds that fed on fish in the water column had less plastic in their stomachs compared to those that were surface eaters [41]. This could be because birds that maintain a diet of zooplankton may be unable to distinguish between plastics and their primary food source due to the plastic pieces' color or shape. Since most adult birds regurgitate what has been ingested as a way to feed their chicks, they pass the bolus containing the plastic pieces onto their young. Birds such as the albatross and shearwater had more plastic in the first region of their stomachs and gizzards, indicating that when these plastics were regurgitated, they would be passed to their young during feeding (Moser and Lee 1992). Juvenile albatross and shearwaters were found to ingest more plastics than adults [49]. Similar to other marine life, swallowed plastic can obstruct and damage a bird's digestive system, reducing its foraging capabilities. Ryan (1988) concluded that ingested plastics could reduce the fitness, growth rate, and food consumption of seabirds, based on the results from a study using domestic chickens (Gallus domesticus). The amount of plastic ingested by different species of birds may be an indicator of the accumulation of plastics in an area [50].

Figure 5: Effects of Plastics on coastal and marine biota: a)

Plastics ingestion by a blue shark: Priona ceglauca of Carlos Canales-Cerro (Thiel et al., 2018; photo authorship: Dr. Carlos Canales-Cerro), b) Attachment on plastic debris by Goose Barnacle, Lepas anserifera (photo authorship:
J.D.M. Senevirathna), c) Partial cover of macroplastic pollutants on Rock Oyster: Saccostrea forskalii colony (photo authorship: J.D.M. Senevirathna), d) Entanglement of nestling in a synthetic plastic string [3].

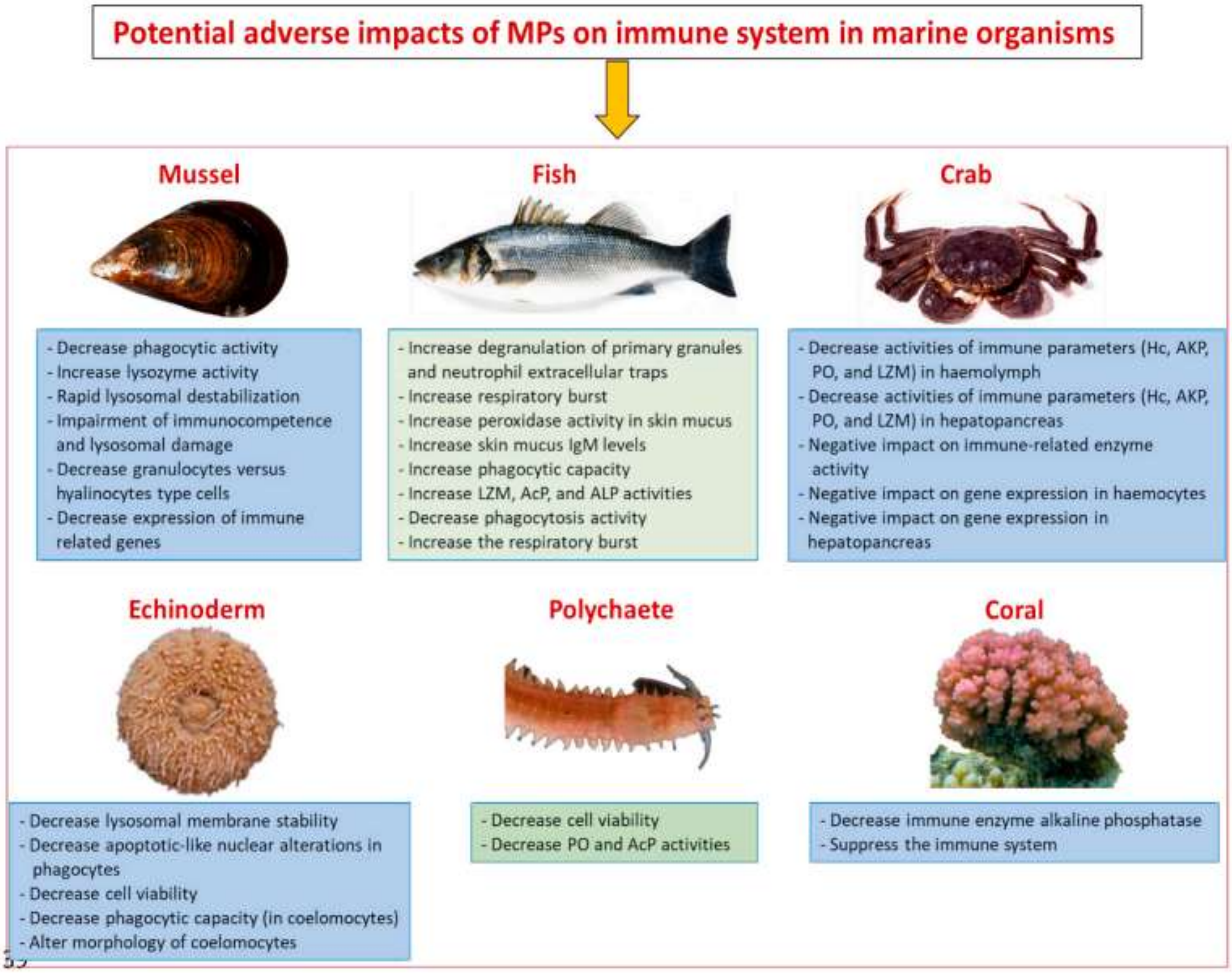
Table 1: Classification of plastic debris is mainly according to their sizes

Classification 1 Micro-debris Meso-debris Macro-debris Mega-debris	< 5 mm 5 – 20 mm > 20 mm > 100 mm	[51]
Classification 2 Microplastics Macroplastics Megaplastics Plastics	1 – 5 mm 5 – 10 mm 10 – 20 mm	[52]
Classification 3 Nanoplastics Small microplastics Large microplastics Mesoplastics Macroplastics	1 – 1000 nm and < 20 (µm) 20 µm – 1mm 1 – 5 mm 5 – 25 mm > 25 mm	[53]

Microplastic impacts on reproduction:

Reproduction is an energetically intensive process and an inadequate nutritional intake can have adverse effects on an organism's fecundity. Reproductive toxicity refers to detrimental impacts on any stage of the marine animals' reproduction cycle such as gametogenesis, gamete and oocyte quality, fecundity, egg production, and sperm swimming speed [54]. Several studies describe the effects of environmental exposure to MPs on marine animals' reproduction. Gamete and oocyte quality, fecundity, and sperm swimming speed were reduced in exposed oysters. These effects significantly affected the quality of offspring and reduced the growth of their larval progeny. Importantly, they observed a decrease in oocyte number (- 38%), oocyte diameter (− 5%), and sperm velocity (- 23%) in oysters exposed to PS-MPs, which may have an impact on the survival of larvae and offspring growth. It was also reported that prolonged exposure to PS-MPs can negatively impact the fecundity of the marine copepod Calanus helgolandicus, where a reduction in hatching success has been observed (Cole et al., 2015). The potential effect of PS-MP exposure on fertilization of sea urchin Paracentrotus lividus was studied by Martínez-Gomez ´ et al. (2017), who reported significant reductions in fertilization success rates following MP exposure. Furthermore, [55] concluded that MP particles from different origins including PA, PE, PP, PE, and PVC significantly reduce reproductive success in nematode Caenorhabditis elegans, while only PE- and PVC-MPs had a significant impact on brood size.

Figure 6: Potential impacts of MP particles on the immune system in marine animals.



LZM: lysozyme; AcP: acid phosphatase; ALP: alkaline phosphatase; Hc: haemo cyanin; AKP: alkaline phosphatase; PO: phenoloxidase [56].

Effects of plastic on the environment:

Several ecologically damaging and hazardous effects on the marine environment are caused due to plastic pollution. Wastewater effluents of the plastic industry are characterized by parameters such as turbidity, pH, suspended solids, BOD, sulfide, and COD. Plastics are the most common elements found in the ocean. It is harmful to the environment as it does not decompose easily and is often ingested as food by marine animals [57]. In the digestive system of these animals, the ingested plastic persists and leads to decreased gastric enzyme secretion, gastrointestinal blockage, decreased feeding stimuli, reproduction problems, and decreased steroid hormone levels. Plastic waste is disposed of by recycling, incineration, and landfill. Incineration and pyrolytic conversion of waste plastic results in the emission of hazardous atmospheric pollutants, including polyaromatic hydrocarbons, CO2 (a greenhouse gas), and persistent organic pollutants like dioxins which cause global warming and pollution [58]. In the ocean organic pollutants are found in high concentrations in plastic particles. The chemicals that are toxic and found in oceanic plastic debris include; nonylphenol (NP), polychlorinated biphenyls (PCBs), and organic pesticides such as bisphenol A (BPA), polycyclic aromatic hydrocarbons (PAHs), dichlorodiphenyltrichloroethane (DDT) and polybrominated diphenyl ethers (PBDEs). Many of these compounds pose risks to wildlife and human health (180). These toxic chemicals cause health problems such as endocrine disruption, breast cancer, neurobehavioral changes, developmental impairment (hormonal imbalances, growth abnormalities, and neurological impairment), arthritis, cancer, DNA hypomethylation, and diabetes [59].

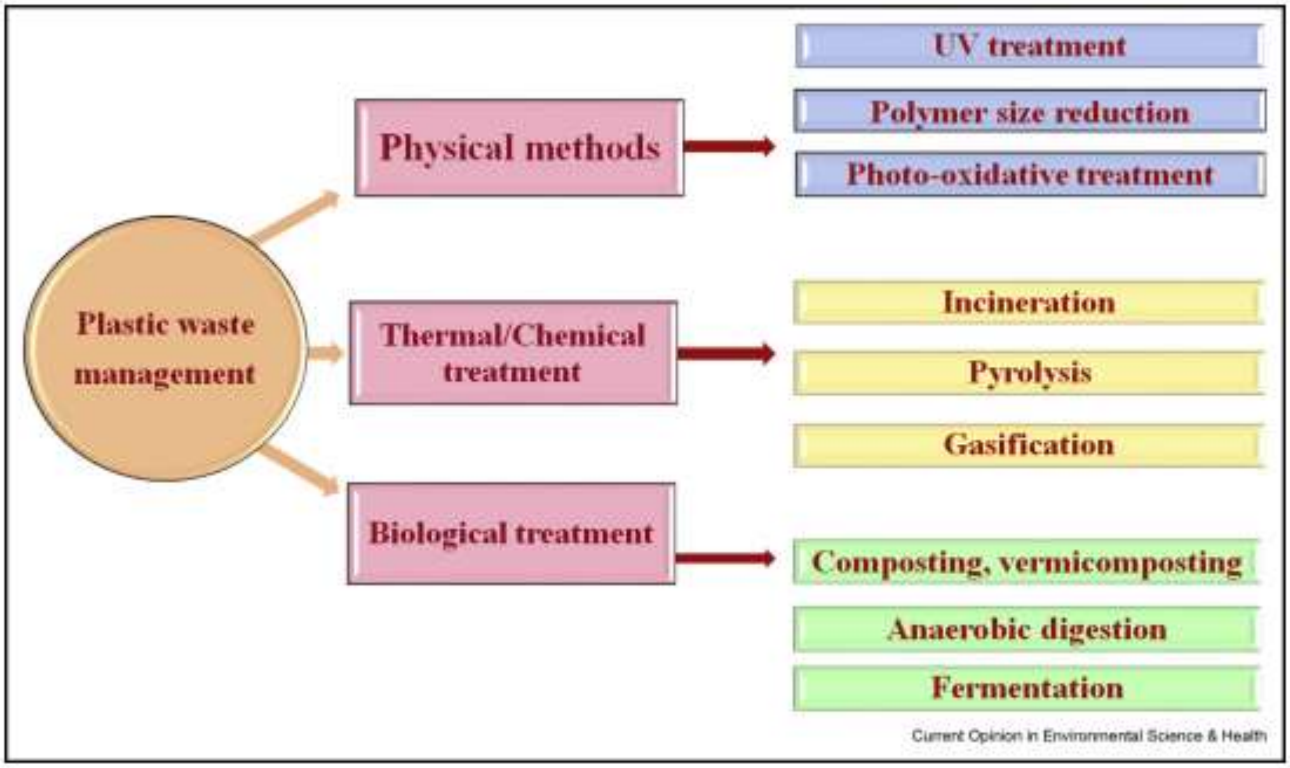
Management Strategies for Plastic Pollution:

Many supermarkets have voluntarily abolished the provision of (free) plastic bags, which has led to notable drops in plastic bag usage [60]. At the same time, alternative bags made of more durable and natural materials, such as cotton, hessian, or linen, are available to consumers. Deposit return strategies have shown high efficiency in reducing waste with return rates of up to 90% in Sweden and Germany. Other interventions such as 'Operation Clean Sweep' organized by non-governmental organizations (NGOs) to clean beaches and drains can help reduce plastic pollution of the environment. The behavioral change towards plastics occurring in society impacts many private companies. For example, globally, the Coca-Cola company is now committed to making 100% of its packaging recyclable by 2025, using at least 50% recycled material in its packaging by 2030, and collecting and recycling a bottle or can for each one sold by 2030. Multinational companies such as Nestlé, PepsiCo, LEGO, etc. have similar targets. In addition to voluntary solutions for reducing plastic waste, the market for ethically produced goods (including recycled products) is growing worldwide, as consumers are becoming more aware of the negative impacts of plastic pollution. Examples of consumer awareness-driven interventions to combat plastic litter include the production of clothes, shoes, skateboards, sunglasses, and swimming gear from derelict fishing gear. Finally, other initiatives are considered to reduce the need for plastics. For instance, public drinking fountains were provided pre-COVID in cities to reduce the need for bottled water. At the same time, buying goods from local farmers' fresh markets is encouraged as a way for customers to lower the packaging volume associated with purchases made elsewhere [61].

Measures to enhance recycling:

There is increasing agreement about the need to rethink the plastics economy to consider key foundations. It must adopt a circular approach to plastics, meaning that the design and production of plastic products should fully respect reuse, repair, and recycling needs, and plastics that are difficult to recycle should be phased out. This has to be done collaboratively, to ensure buy-in and sustainable adoption. In addition, the plastic economy must support national economies and livelihoods through job creation, economic growth, investment, and social fairness. Finally, it must foster collaboration, by bringing the private sector, national and regional authorities, cities, and consumers towards a set of common goals [62].To achieve these targets, there is pressure on industries and retailers to strive to reduce plastic packaging and to design products containing plastics in a way that simplifies recycling. Policy tools for effectively incentivizing the adoption of recycling options include • Policies targeting the increased adoption of recycled products, e.g. preferential rates for reuse products or policies supporting the creation of a domestic market for recovery and recycling. This has proven successful in the past in other fields, e.g. to drive the adoption of incineration technologies in Europe. • Zero landfilling policies or policies targeting the reduction of the amounts of plastic waste discarded or abandoned. • Policies promoting sustainable practices through tax abatement and fee reductions or application of levies [63]

Figure 7: Technologies available for solid waste management [64].



Conclusion:

Marine plastic pollution has emerged as a pervasive environmental crisis with significant consequences for aquatic wildlife and ecosystem health. Plastics, ranging from large debris to microplastics, are infiltrating marine environments at an alarming rate, driven by human activities, improper waste management, and insufficient global regulations. These pollutants not only harm marine organisms through ingestion, entanglement, and habitat degradation but also disrupt critical ecological processes and food webs.Aquatic species, from plankton to apex predators, face threats from toxic chemical leaching, bioaccumulation, and physiological stress caused by plastics. Ecosystem health is further jeopardized as plastics alter sediment properties, reduce biodiversity, and impair essential ecosystem services like nutrient cycling and water purification. The consequences extend to human communities, affecting fisheries, tourism, and overall oceanic health, with far-reaching socio-economic impacts. Addressing marine plastic pollution requires a multifaceted approach involving international collaboration, stricter regulations, innovative waste management technologies, and a shift towards a circular economy. Public awareness and behavioral change are equally critical in reducing plastic usage and promoting sustainable alternatives. Ultimately, mitigating marine plastic pollution is not only about protecting marine life but also ensuring the resilience of ecosystems vital for global biodiversity, climate stability, and human well-being. The collective responsibility of governments, industries, and individuals is paramount in combating this pressing environmental challenge.

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