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Review Article

Post-Covid-19 Pandemic Awareness on The Use of Micro- and Nano Plastic and Efforts into Their Degradation - A Mini Review

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ABSTRACT

Micro- and nano plastic pollution poses a global threat and causes a future problem, and needs greater global attention. Its pollution is exacerbated recently by the excessive use of plastic polymers to prevent and handle the COVID-19 pandemic at a global scale. This review covered the major concerns about the characteristics, effect, and bioremediation of micro-and nano plastics. Many aquatic organisms easily ingest micro-and nano plastic at different trophic levels. This ingestion caused negative health impacts to all living organisms. Microplastic directly affects living organisms like mechanical injury, false satiation, declined growth, promoted immune response, and energy loss. Other debilitating effects include disrupted enzyme activity and production, decreased fecundity, oxidative stress, and mortality. Nano plastic could enter the circulatory system and caused negative effects on the cellular and molecular levels. Bioremediation of microplastic by selected higher and lower eukaryotes, bacteria, fungus, and algae on several polymers was previously reported. However, not much literature is available on nano plastic biodegradation. Therefore, the current review will focus on the characteristics, effect, and bioremediation effort of micro-and nano plastic.

Keywords: Biodegradation, COVID-19, Microplastic, Nano plastic, Pollution.

Introduction

Today, plastic has been a global problem, especially for aquatic ecosystems. After their first commercial development in the 1930s and 1940s, plastics became widespread because of their convenience, durability, and low cost [1]. The world plastic production reached 288 million in 2012, a 620% increase since 1975 [2]. The plastic industry grew rapidly up to 335 million tons in 2016 [3].

During the COVID-19 pandemic, research showed a decrease in air pollution in China [4], India [5], Rio de Janeiro [6], and Sao Paolo [7]. On the other hand, the COVID-19 pandemic causes a serious problem about the plastic used by many people in various working and healthcare personnel. During a pandemic, the demand for face masks, gloves, coveralls, gowns, goggles, and face shields has been increased dramatically [8]. It will be a serious problem for the environment during post-COVID-19.

COVID-19 started in Wuhan, China, where 116 million personal protective equipment (PPE) was needed per day or about 12 times the usual condition [9]. If the global population uses a standard disposable face mask (one per day), this produces a monthly wastage of 129 billion face masks and 65 billion gloves [10]. Until February 2020 last year, to complete this demand, China intensified its daily production of medical masks to 14.8 million [11]. In April 2020, The Japanese Ministry of economy, trade, and industry (METI) ordered

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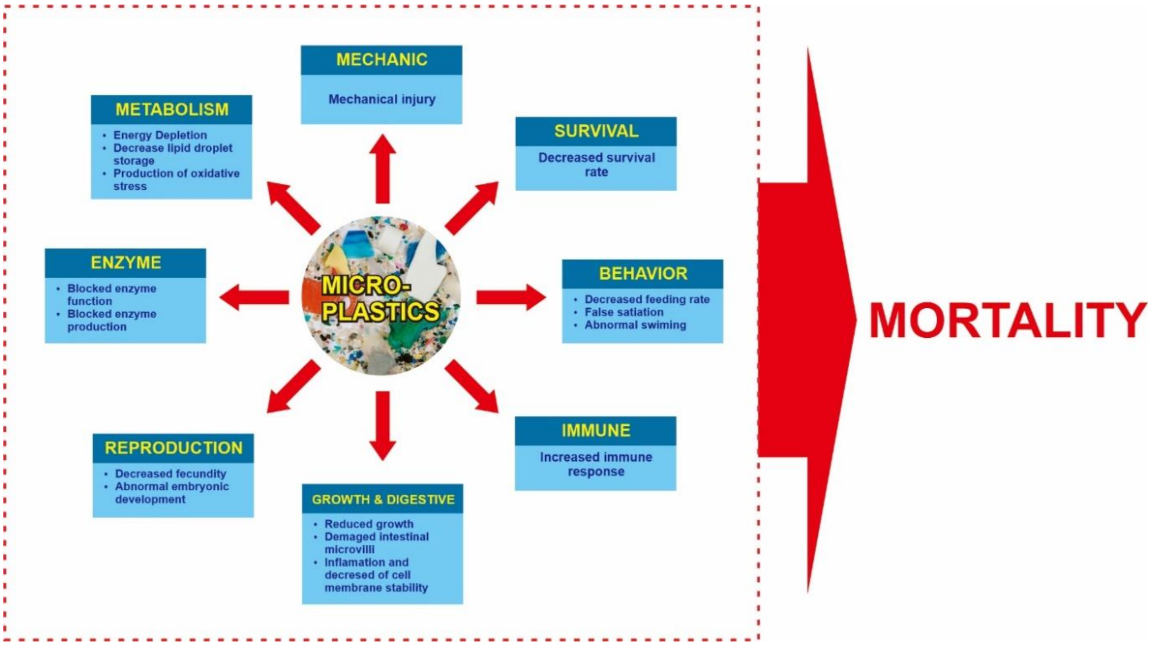

Figure 1. Effect of microplastic on organism

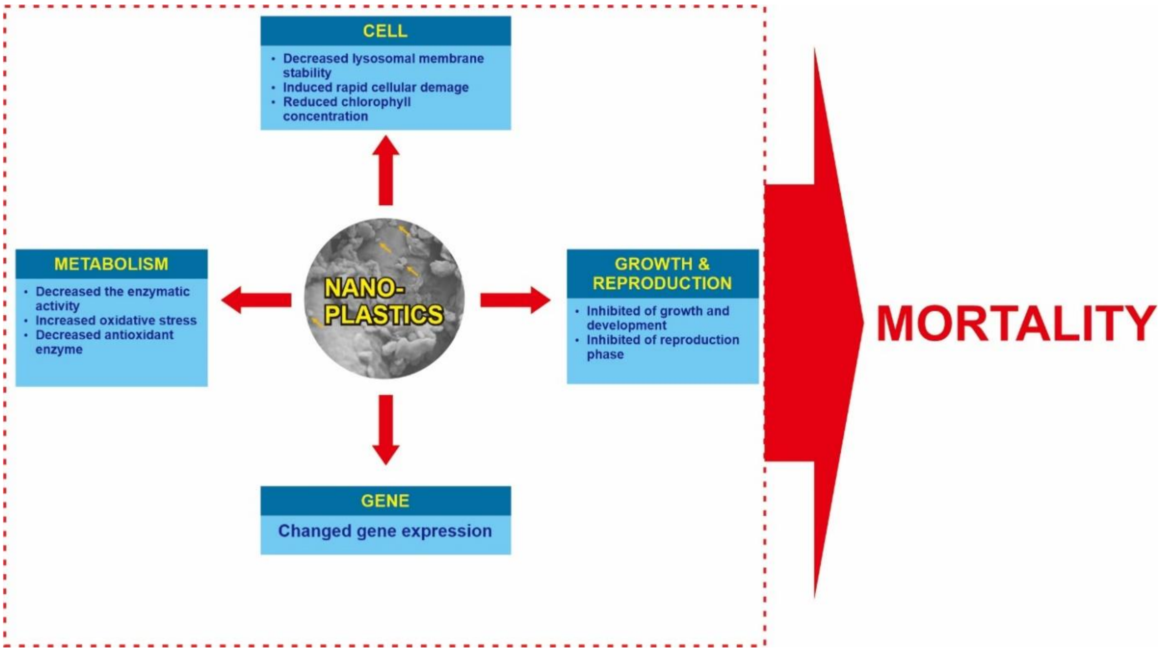

Figure 2.Effect of nano plastic to different organism

face masks per month over 600 million [12].

A dramatic increase in medical waste was also reported in Catalonia and Spain (350% and 370%, respectively) [13]. About 5336–38426 million face masks were estimated for Saudi Arabia. The total microplastic content from Bahrain and Qatar was 1.7–12.3 and 3.10–22.31 thousand tons, respectively [14]. On the other hand, Singapore was produced 1,400 tons of plastic waste from package take-out meals and home-delivered groceries during an 8-week lockdown [15]. All this plastic waste generated at a global scale will end up in landfilled or incinerated, leading to higher negative environmental impacts. Very minor of these wastes were sent to the recycling plant because plastic mixtures were difficult to recycle because of their natural characteristics. Current estimations of 4–12 million tonnes/year of plastics go into the seas and oceans without properly treated [16].

There were two polymer characteristics of plastic: thermoplastic (can be molded repeatedly on heating), such as polyethylene terephthalate (PET), polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), and polystyrene (PS); and thermosets (once formed, cannot be heated and remolded), such as polyurethane (PUR) and epoxy resins for coatings [17]. Large plastic pieces were degraded to micro-and nano plastic size particles by various mechanisms, such as physicochemical and biological degradation [18, 19].

Micro- and Nano plastic

The microplastic were spread all over the oceans [20, 21], lands [22], and freshwaters like rivers and lakes [23]. Microplastics consist of numerous size-ranges; diameters of <10 mm [24], <5 mm [25], 2–6 mm [26], <2 mm [27] and <1 mm [28]. Microplastics can be described according to the main categories are fragments (rounded and angular), pellets (cylinders, disks, and spherules), filaments (fibers), and granules.

Nano plastic was referred to any particles smaller than 100 nm, or the upper limit to 1 µm and with a Brownian motion (random motion of particles suspended in a medium) in the aqueous system [29]. Nano plastics with high surface reactivity could, directly and indirectly, affect soil ecosystems and in all habitats, including groundwaters and surprisingly at the north Atlantic subtropical gyre [30]. The gyre itself is part of 75% of the open ocean on earth. Nano plastics were formed by degradation of polyethylene (PE) and polypropylene (PP) by UV irradiation [31] and on disposable polystyrene (PS) cup lids [32] or by physical mechanism [33].

Effect of Microplastic on Aquatic Organism

Microplastics' sizes make them easily ingested by a lot of aquatic organisms at different trophic levels [34]. The ingestion can cause negative health impacts (Figure 1).

Microplastics were also found in ostracods (*Notodromas monacha*), annelids (*Lumbriculus variegatus*), gastropods (*Potamopyrgus antipodarum*), and crustaceans (*Gammarus pulex* and *Daphnia magna*) [35]. The effects of microplastics on zooplankton crustaceans include abnormal embryonic development, decreased lipid droplet storage, decreased feeding rates, energy depletion [36], and decreased survival [37]. Some studies also observed reduced growth [38], altered reproduction [36, 38], delay in molting [39], abnormal swimming behavior [38], and damaged intestinal microvilli [40]. Microplastics reduce growth, reproduction [41], assimilation efficiency [42], and a mortality increase that was exponential to the exposure dose on amphipods [43]. Microplastics ingestion by *Mytilus edulis* can cause tissue inflammation and decrease cell membrane stability of the digestive system [48]. *Oryzias latipes* fed polyethylene exhibit bioaccumulation, liver glycogen depletion, fatty vacuolation, and single-cell necrosis, and early tumor formation [49]. Microplastics can cause nuclear membrane disruption, oxidative stress, the release of damage-associated molecular patterns [44].

The effects of microplastics on organisms can be divided into chemical and physical mechanisms. Chemical effects of microplastics involve the absorption of other contaminants on the surface or the release of plastic monomers if they physically interact with the organisms' tissues [45]. Microplastics can be found on the gastrointestinal tract of fish, gills, liver, and muscle of wild specimens [46]. Effect of microplastics on zebrafish (*Danio rerio*) liver was shown on induction of anti-oxidative enzyme activity, the alteration of metabolism, tissue inflammatory [47] immune response activation, and increase of genes regulation related to the complement system [50].

Microplastics accumulate waterborne contaminants including metals (Al, Fe, Sn, Cu, Zn, Cd, U, Sb) [51], nonylphenol and bisphenol A [52], and bio-stabilization, bioaccumulation, and toxic compounds [54]. Microplastics can be a vector for human waterborne pathogens (Genus *Vibrio*) influencing the water quality [55].

Effect of Nano plastic on Aquatic Organism

Nano plastic can enter the circulatory system and cause negative effects at cellular and molecular levels (Figure 2). Nano plastics can be easily adsorbed by green algae and affect the microbe's photosynthetic mechanism [56]. Nano plastics can accumulate in the digestive tract of sea urchin [53], while polystyrene-NH_2 nano plastics could attach with lipid bilayers on the cell membrane. -NH_2 could also decrease lysosomal membrane stabilization, increase oxyradical production in hemolymph serum, and induce rapid cellular damage (membrane blebbing and loss of filopodia) [57].

Nano plastics changed the mussel's (*Mytilus galloprovincialis*) expression of the gene and decreased enzymatic activity. Other induced effects include disrupted neurotransmission, increased the oxidative status and peroxidative damage [58]. Also, nano plastics could increase regulation in the central nervous system and inhibit acetylcholinesterase activity of zebrafish (*Danio rerio*) significantly [59].

Nano plastics cause the overexpression of reactive oxygen species (ROS), inhibited the development, growth, and reproduction of *Daphnia pulex*. Low nano plastics (0.1 and 0.5 $mg.l^{-1}$) were caused by overexpression of the MAPK pathway genes, HIF-1 pathway, Cu,Zn-superoxide dismutase (SOD), and activity of glutathione-S-transferase. Antioxidant enzymes such as catalase, SOD, and Cu, Zn-SOD were decreased after exposure to nano plastics [60]. Nano plastics could reduce population growth and chlorophyll concentrations in the green alga *Scenedesmus obliquus*. For *Daphnia*, nano plastics could reduce its body size and disturbed reproduction system [61].

Increased nano plastics concentration in *Macrobrachium nipponense* effect decreased antioxidant enzymes and increased lipid peroxidation and hydrogen peroxide. The activities of non-specific immune enzymes increased and then decreased when nano plastics concentration increased. Similarly, the expressions of immune-related genes generally increased and then decreased [62; 63].

Accumulation of nano plastics on *Corbicula fluminea* occurred in the mantle, visceral mass, and gill. This accumulation of nano plastic also produces oxidative stress that causes oxidative damage to the liver, neuron, and intestine by antioxidation system imbalance [64].

Bioremediation of Micro- and Nano plastic

The microbial micro-and nano plastic degradation is a multistep process involving biodeterioration (changing the physio-chemical properties of the polymer by an enzyme), bio-fragmentation (reduction of the complex into a simpler polymer by enzymes or acids), assimilation (merger of the molecules by microorganisms), and mineralization (oxidized metabolites produced by degradation) [65]. UV radiation and photooxidation can increase bioremediation [66, 67].

The previously reported microplastic degradation by selected microorganisms is listed in Table 1. Past research has been focused on bacteria and lower eukaryotes (fungi) as bioremediation agent [68]. Many literatures have shown that unicellular microalgae, single species or consortia with bacteria can degrade endocrine disrupting chemicals like microplastics in wastewaters. Seaweeds like *Fucus vesiculosus* are also good plastic degraders as they can remain suspended on the water surface [69].

Several freshwater Magnoliophyta such as *Eichhornia crassipes*, *Pistia stratiotes*, and *Lemna minor* were used for removing heavy metals and several pollutants in Waste Water Treatment Plants (WWTPs) [70]. In addition, higher eukaryotes have potential for elimination of microplastics from WWTPs for instance annelids (sandworms), echinoderms (sea cucumbers) and some other animals that still under investigation. Seagrasses and macrophytes seem to be good candidates as well for future consideration. [71].

Microorganisms like *Rhodococcus ruber* [72] and fungus *Penicillium simplicissimum* [73] able to degrade polyethylene (PE) by producing an extracellular enzyme. The thermophilic bacterium

Table 1. Selected microorganisms for microplastic degradation

No.	Species Organism	Type	Ref.
1	*Fucus vesiculosus*	Algae	[69]
2	*Egeria densa*	Macrophytes	[71]
3	*Brevibacillus borstelensis*	Bacteria	[66]
4	*Streptomyces* sp.	Bacteria	[74, 75]
5	*Pseudomonas stutzeri*	Bacteria	[75]
6	*Pseudomonas chlororaphis*	Bacteria	[80]
7	*Pseudomonas putida*	Bacteria	[81]
8	*Alcaligenes faecalis*	Bacteria	[75, 76]
9	*Clostridium botulinum*	Bacteria	[75]
10	*Rhodococcus ruber*	Bacteria	[73]
11	*Aureobasidium pullulans sp*	Bacteria	[79]
12	*Bacillus brevis*	Bacteria	[78]
13	*Bacillus cereus*	Bacteria	[83]
14	*Rhodococcus ruber*	Bacteria	[82]
15	*Comamonas testosteroni* F4	Bacteria	[84]
16	*Delftia sp.* WL-3	Bacteria	[85]
17	*Ideonella sakaiensis*	Bacteria	[87]
18	*Fusarium* sp.	Fungi	[77]
19	*Fusarium moniliforme*	Fungi	[77]
20	*Fusarium solani*	Fungi	[79]
21	*Penicillium roqueforti*	Fungi	[77]
22	*Penicillium simplicissimum*	Fungi	[73]
23	*Aspergillus flavus PEDX3*	Fungi	[88]

Brevibacillus borstelensis [66] and *Streptomyces* sp. can also degrade the same polymers [74]. *Alcaligenes faecalis, Streptomyces* sp., and *Pseudomonas stutzeri* [75, 76] can degrade polyhydroxyalkanoates (PHA) and polyhydroxy butyrate (PHB). PHA also can be degraded by fungi that have been isolated from soil (Basidiomycetes, Deuteromycetes, and Ascomycetes) [77].

Polycaprolactone (PCL) is easily degraded by *Alcaligenes faecalis* [76] and *Clostridium botulinum* [75], and *Fusarium* [77]. Polylactic acid (PLA) is degraded by *Bacillus brevis* [78], *Fusarium moniliforme,* and *Penicillium roqueforti* [73, 77].

Polyurethane is degraded by *Fusarium solani*, *Aureobasidium pullulans* sp., [79], and *Pseudomonas chlororaphi* [80]. Polyvinyl chloride (PVC) could be degraded by the *Pseudomonas putida* [81], whereas polystyrene by the actinomycete *Rhodococcus ruber* [82].

After 40 days, *Bacillus cereus* was reported to degrade 1.6% polyethylene (PE), 6.6% Polyethylene terephthalate (PET), and 7.4% polystyrene (PS). *Bacillus gottheilii* could degrade 6.2% polyethylene (PE), 3.0% polyethylene terephthalate (PET), 3.6% polypropylene (PP), and 5.8% polystyrene (PS) [83]. A combination of *Comamonas testosteroni* F4 and high pH showed effective degradation of PET [84]. *Delftia* sp. WL-3 can also consume 94% of 5 $g.l^{-1}$ of diethyl terephthalate (DET) as a carbon source in 7 days [85].

Biodegradation of nano plastic is a relatively new issue. Degradation of nano plastics still using an OH-mediated degradation process. This method could affect the ecosystems by increasing the amount of dissolved organic matter [86].

Conclusion

Microplastics and nano plastics have been shown serious effects on organisms ranging from genes to behavior. Bioremediation efforts are required to solve the microplastic and nano plastic problems, let alone reducing their utilization at the consumer's level. Microplastic bioremediation can be carried out by various organisms like algae, bacteria, and fungi. However, nano plastics are difficult to degrade. Nano plastics can disrupt the activity of organisms down to the level of genes and proteins. This may be difficult for many organisms to anticipate and, therefore, open for further research. On the other hand, fungi for microplastic bioremediation are still limited and require further exploration and research efforts, especially at genomic and proteomic levels. Currently, post-COVID-19 derails efforts to reduce plastic utilization and plastic consumption. At the same time, its global production is expected to increase continuously. Recently, there has been a high number of scientific papers related to microplastic and little on nano plastic degradation. This may fill the knowledge gap regarding current occurrence level, fate, and environmental and health impacts.

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Reference

1. Monteiro RCP, Ivar do Sul JA, Costa MF (2018) Plastic pollution in islands of the Atlantic Ocean. Environmental Pollution 238: 103–110. doi: 10.1016/j.envpol.2018.01.096.
2. Plastics Europe (2013) Plastics – the facts 2013 (Plastics Europe, Brussels, Belgium, 2013) www.plasticseurope.org/Document/plastics-the-facts-2013.aspx?FolID=2. Accessed date: 2020.
3. Plastics Europe (2017) Plastic - the Facts 2017. http://www.Plasticseurope.org/application/files/5717/1717/4180/Plastics the facts 2017 FINAL for website one page.pdf. Accessed date: 2020.
4. Wang Q, Su M (2020) A preliminary assessment of the impact of COVID-19 on environment – A case study of China. Science of the Total Environment 728: 138915. doi: 10.1016/j.scitotenv.2020.138915.
5. Sharma S, Zhang M, Anshika et al. (2020) Effect of restricted emissions during COVID-19 on air quality in India. Science of the Total Environment 728: 138878. doi: 10.1016/j.scitotenv.2020.138878.
6. Dantas G, Siciliano B, França B et al. (2020) The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. Science of the Total Environment 729: 139085. doi: 10.1016/j.scitotenv.2020.139085.
7. Nakada LYK, Urban RC (2020) COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo state, Brazil. Science of the Total Environment 730: 139087. doi: 10.1016/j.scitotenv.2020.139087.
8. WHO (2020) Shortage of Personal Protective Equipment Endangering Health Workers Worldwide. Newsroom, March, 3, 2020.
9. Bermingham F, Tan SL (2020) Economy / Global Economy Coronavirus: China' s mask-making juggernaut cranks into gear, sparking fears of over-reliance on world' s workshop. South China Morning Post.

https://www.scmp.com/economy/global-economy/article/3074821/coronavirus-chinas-mask-making-juggernaut-cranks-gear. Accessed date: 2020
10. Prata JC, Silva ALP, Walker TR, et al. (2020) COVID-19 Pandmic Repercussions on the Use and Manaement of Plastics. Environmental Science and Technology, 54 (13): 7760–7765. doi: 10.1021/acs.est.0c02178.
11. Xinhua (2020) China Focus: Mask makers go all out in fight against novel coronavirus. Xinhuanet. http://www.xinhuanet.com/english/2020-02/06/c_138760527.htm. Accessed date: 2020
12. METI. 2020) Current Status of Production and Supply of Face Masks, Antiseptics and Toilet Paper / METI Ministry of Economy, Trade and Industry. https://www.meti.go.jp/english/covid-19/mask.html. Accessed date: 2020
13. Klemeš JJ, Fan YV, Tan RR, Jiang P (2020) Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. Renewable and Sustainable Energy Reviews 127 (April). doi: 10.1016/j.rser.2020.109883.
14. Akber SA, Khalil AB, Arslan M (2020) Extensive use of face masks during COVID-19 pandemic: (micro-)plastic pollution and potential health concerns in the Arabian Peninsula. Saudi Journal of Biological Sciences 27 (12): 3181–3186. doi: 10.1016/j.sjbs.2020.09.054.
15. Bengali S (2020) The COVID-19 pandemic is unleashing a tidal wave of plastic waste. The Los Angeles Times, 1–16. https://www.latimes.com/world-nation/story/2020-06-13/coronavirus-pandemic-plastic-waste-recycling. Accessed date: 2020
16. Patrício ALS, Prata JC, Walker TR et al. (2021) Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations. Chemical engineering journal (Lausanne, Switzerland: 1996) 405: 126683. doi: 10.1016/j.cej.2020.126683.
17. Rhodes CJ (2018) Plastic pollution and potential solutions. Science Progress 101 (3): 207–260. doi: 10.3184/003685018X15294876706211.
18. Cole M, Lindeque P, Halsband C, Galloway TS (2011) Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin, 62(12), 2588–2597. doi: 10.1016/j.marpolbul.2011.09.025.
19. Urbanek AK, Rymowicz W, Mirończuk AM (2018) Degradation of plastics and plastic-degrading bacteria in cold marine habitats. Applied microbiology and biotechnology 102 (18): 7669–7678. doi: 10.1007/s00253-018-9195-y.
20. Thomson RC, Moore CJ, Saal FSV, Swan SH (2009) Plastics, the environment and human health: Current consensus and future trends. Philosophical Transactions of the Royal Society B: Biological Sciences 364 (1526): 2153–2166. doi: 10.1098/rstb.2009.0053.
21. Bagaev A, Mizyuk A, Khatmullina L et al. (2017) Anthropogenic fibres in the Baltic Sea water column: Field data, laboratory and numerical testing of their motion. Science of the Total Environment 599–600: 560–571. doi: 10.1016/j.scitotenv.2017.04.185.
22. Li X, Mei Q, Chen L et al. (2019) Enhancement in adsorption potential of microplastics in sewage sludge for metal pollutants after the wastewater treatment process. Water Research 157: 228–237. doi: 10.1016/j.watres.2019.03.069.
23. Ballent A, Corcoran PL, Madden O et al. (2016) Sources and sinks of microplastics in Canadian Lake Ontario nearshore, tributary and beach sediments. Marine Pollution Bulletin 110 (1): 383–395. doi: 10.1016/j.marpolbul.2016.06.037.
24. Graham ER, Thompson JT (2009) Deposit- and suspension-feeding sea cucumbers (Echinodermata) ingest plastic fragments. Journal of Experimental Marine Biology and Ecology 368 (1): 22–29. doi: 10.1016/j.jembe.2008.09.007.
25. Barnes DKA (2002) Biodiversity: invasions by marine life on plastic debris. Nature 416 (6883): 808–809.
26. Derraik JGB (2002) The pollution of the marine environment by plastic debris: a review. Marine Pollution Bulletin 44 (9): 842–852.
27. Ryan PG, Moore CJ, van Franeker JA, Moloney CL (2009) Monitoring the abundance of plastic debris in the marine environment. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 1999–2012.
28. Claessens M, de Meester S, van Landuyt L et al. (2011) Occurrence and distribution of microplastics in marine sediments along the Belgian coast. Marine Pollution Bulletin 62 (10): 2199–2204. doi: 10.1016/j.marpolbul.2011.06.030.
29. Gigault J, ter Halle A, Baudrimont M et al. (2018) Current opinion: What is a nano plastic? Environmental Pollution 235: 1030–1034. doi: 10.1016/j.envpol.2018.01.024.
30. ter Halle A, Jeanneau L, Martignac M et al. (2017) Nano plastic in the North Atlantic subtropical gyre. Environmental Science & Technology 51: 13689–13697.
31. Gigault J, Pedrono B, Maxit B, ter Halle A (2016) Marine plastic litter: the unanalyzed nano-fraction. Environmental Science: Nano 2: 346–350.
32. Lambert S, Wagner M (2016) Characterisation of nano plastics during the degradation of polystyrene. Chemosphere 145: 265–268. doi: 10.1016/j.chemosphere.2015.11.078
33. Ekvall MT, Lundqvist M, Kelpsiene E et al. (2019) Nano plastics formed during the mechanical breakdown of daily-use polystyrene products. Nanoscale Advances, 1 (3): 1055–1061. doi: 10.1039/c8na00210j.
34. Wright SL, ThoMicroplasticson RC, Galloway TS (2013) The physical impacts of microplastics on marine organisms: a review. Environmental Pollution (Barking, Essex: 1987) 178: 483–492. doi: 10.1016/j.envpol.2013.02.031.
35. Imhof HK, Ivleva NP, Schmid J et al. (2013) Contamination of beach sediments of a subalpine lake with microplastic particles. Current Biology 23 (19): R867–R868. doi: 10.1016/j.cub.2013.09.001.
36. Cole M, Lindeque P, Fileman E et al. (2015) The Impact of Polystyrene Microplastics on Feeding, Function and Fecundity in the Marine Copepod Calanus helgolandicus. Environmental Science & Technology 49 (2): 1130–1137.
37. Manfra L, Rotini A, Bergami E et al. (2017) Comparative ecotoxicity of polystyrene nanoparticles in natural seawater and reconstituted seawater using the rotifer Brachionus plicatilis. Ecotoxicology and Environmental Safety 145 (May): 557–563. doi: 10.1016/j.ecoenv.2017.07.068.
38. Ziajahromi, S., Kumar, A., Neale, P. A., & Leusch, F. D. L. (2018) Environmentally relevant concentrations of

polyethylene microplastics negatively impact the survival, growth and emergence of sediment-dwelling invertebrates. Environmental Pollution 236: 425–431. doi: 10.1016/j.envpol.2018.01.094.

39. Jeong CB, Kang HM, Lee MC et al. (2017) Adverse effects of microplastics and oxidative stress-induced MAPK/Nrf2 pathway-mediated defense mechanisms in the marine copepod Paracyclopina nana. Scientific Reports 7 (January): 1–11. doi: 10.1038/srep41323.
40. Chae Y, Kim D, Kim SW, An YJ (2018) Trophic transfer and individual impact of nano-sized polystyrene in a four-species freshwater food chain. Scientific Reports 8 (1): 1–11. doi: 10.1038/s41598-017-18849-y.
41. Redono-Hasselerharm PE, Falahudin D, Peeters ETHM, Koelmans AA (2018) Microplastic Effect Thresholds for Freshwater Benthic Macroinvertebrates. Environmental Science and Technology 52 (4): 2278–2286. doi: 10.1021/acs.est.7b05367.
42. Blarer P, Burkhardt-Holm P (2016) Microplastics affect assimilation efficiency in the freshwater amphipod Gammarus fossarum. Environmental Science and Pollution Research 23: 23522–23532.
43. Au SY, Bruce TF, Bridges WC, Klaine SJ (2015) Responses of Hyalella azteca to acute and chronic microplastic exposures. Environmental Toxicology 34 (11): 2564–2572.
44. Hwang J, Choi D, Han S et al. (2020) Potential toxicity of polystyrene microplastic particles. Scientific Reports 10 (1): 1–12. doi: 10.1038/s41598-020-64464-9.
45. Yong CQY, Valiyaveetill S, Tang BL (2020) Toxicity of microplastics and nano plastics in Mammalian systems. International Journal of Environmental Research and Public Health 17 (5). doi: 10.3390/ijerph17051509.
46. Abbasi S, Soltani N, Keshavarzi B et al. (2018) Microplastics in different tissues of fish and prawn from the Musa Estuary, Persian Gulf. Chemosphere, 205, 80–87. doi: 10.1016/j.chemosphere.2018.04.07651.
47. Lu Y, Zhang Y, Deng Y et al. (2016) Uptake and Accumulation of Polystyrene Microplastics in Zebrafish (Danio rerio) and Toxic Effects in Liver. Environmental Science & Technology 50 (7): 4054–4060.
48. Von Moos N, Burkhardt-Holm P, Köhler A (2012) Uptake and Effects of Microplastics on Cells and Tissue of the Blue Mussel Mytilus edulis L. after an Experimental Exposure. Environmental Science & Technology, 46 (20): 11327–11335.
49. Rochman CM, Hoh E, Kurobe T, The SJ (2013) Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. Scientific Reports 3: 1–7. doi: 10.1038/srep03263.
50. Venema WJ, Spaink HP, Brun NR, Vijver MG (2017) Pathway analysis of systemic transcriptome responses to injected polystyrene particles in zebrafish larvae. Aquatic Toxicology 190 (June): 112–120. doi: 10.1016/j.aquatox.2017.06.014.
51. Ashton K, Holmes L, Turner A (2010) Association of metals with plastic production pellets in the marine environment. Marine Pollution Bulletin 60 (11): 2050–2055. doi: 10.1016/j.marpolbul.2010.07.014.
52. Fries E, Zarfl C (2012) Sorption of polycyclic aromatic hydrocarbons (PAHs) to low- and high-density polyethylene (PE) Environmental Science and Pollution Research 19: 1296–1304.
53. Della TC, Bergami E, Salvati A et al. (2014) Accumulation and Embryotoxicity of Polystyrene Nanoparticles at Early Stage of Development of Sea Urchin Embryos Paracentrotus lividus. Environmental Science & Technology 48 (20): 12302–12311.
54. Koelmans AA, Besseling E, Wegner A, Foekema EM (2013) Plastic as a Carrier of POPs to Aquatic Organisms: A Model Analysis. Environmental Science & Technology 47 (14): 7812–7820.
55. Zettler ER, Mincer TJ, Linda A (2013) Life in the "Plastisphere": Microbial Communities on Plastic Marine Debris. Environmental Science & Technology 47 (13): 7137–7146.
56. Bhattacharjee S, Ershov D, Islam MA et al. (2014) Role of membrane disturbance and oxidative stress in the mode of action underlying the toxicity of differently charged polystyrene nanoparticles. RSC Advances 4 (37): 19321–19330. doi: 10.1039/c3ra46869k.
57. Canesi L, Ciacci C, Fabbri R et al. (2016) Interactions of cationic polystyrene nanoparticles with marine bivalve hemocytes in a physiological environment: Role of soluble hemolymph proteins. Environmental Research 150: 73–81. doi: 10.1016/j.envres.2016.05.045.
58. Brandts I, Teles M, Gonçalves AP et al. (2018) Effects of nano plastics on Mytilus galloprovincialis after individual and combined exposure with carbamazepine. Science of the Total Environment 643: 775–784. doi: 10.1016/j.scitotenv.2018.06.257.
59. Chen Q, Yin D, Jia Y et al. (2017) Enhanced uptake of BPA in the presence of nano plastics can lead to neurotoxic effects in adult zebrafish. Science of the Total Environment 609: 1312–1321. doi: 10.1016/j.scitotenv.2017.07.144.
60. Liu Z, Huang Y, Jiao Y et al. (2020) Polystyrene nano plastic induces ROS production and affects the MAPK-HIF-1/NFkB-mediated antioxidant system in Daphnia pulex. Aquatic Toxicology 220 (January): 105420. doi: 10.1016/j.aquatox.2020.105420.
61. Besseling E, Wang B, Lürling M, Koelmans AA (2014) Nano plastic Affects Growth of S. obliquus and Reproduction of D. magna. Environmental Science & Technology 48 (20): 12336–12343.
62. Wagner M, Scherer C, Alvarez-Muñoz D et al. (2014) Microplastics in freshwater ecosystems: what we know and what we need to know. Environmental Sciences Europe 26 (12): 1–9. doi: 10.1016/0163-8343(83)90040-3.
63. Li Y, Liu Z, Li M et al. (2020) Effects of nano plastics on antioxidant and immune enzyme activities and related gene expression in juvenile Macrobrachium nipponense. Journal of Hazardous Materials 398 (May): 122990. doi: 10.1016/j.jhazmat.2020.122990.
64. Li Z, Feng C, Wu Y, Guo X (2020) Impacts of nano plastics on bivalve: Fluorescence tracing of organ accumulation, oxidative stress and damage. Journal of Hazardous Materials 392 (December 2019): 122418. doi: 10.1016/j.jhazmat.2020.122418.
65. Dussud C, Ghiglione JF (2014) Bacterial degradation of synthetic plastics. In CIESM Workshop Monograph (p. 49e54)
66. Hadad D, Geresh S, Sivan A (2005) Biodegradation of polyethylene by the thermophilic bacterium Brevibacillus borstelensis. Journal of Applied Microbiology, 98(5), 1093–1100. doi: 10.1111/j.1365-2672.2005.02553.x.

67. Sharma M, Sharma P, Sharma A, Chandra S (2015) Initial depletion and subsequent recovery of spermatogonia of the mouse after 20 r of gamma rays and 100, 300, and 600 r of x-rays. CIBTech Journal of Microbiology 4 (1): 85–89. htps://doi.org/10.2307/3570749.
68. Nuzzo A, Puccio S, Martina C et al. (2020) Containment of a genetically modified microorganism by an activated ludge system. New Biotechnology 55 (Octobe 2019): 58–64. doi: 10.1016/j.nbt.2019.10.001.
69. Gutow L, Eckerlebe A, Giménez L, Saborowski R (2016) Experimental Evaluation of Seaweeds as a Vector for Microplastics into Marine Food Webs. Environmental Science & Technology 50 (2): 915–923.
70. Ali S, Abbas Z, Rizwan M et al. (2020) Application of floating aquatic plants in phytoremediation of heavy metals polluted water: A review. Sustainability (Switzerland) 12 (5): 1–33. doi: 10.3390/su12051927.
71. Masiá P, Sol D, Ardura A et al. (2020) Bioremediation as a promising strategy for microplastics removal in wastewater treatment plants. Marine Pollution Bulletin 156: (111252). doi: 10.1016/j.marpolbul.2020.111252.
72. Orr IG, Hadar Y, Sivan A (2004) Colonization, biofilm formation and biodegradation of polyethylene by a strain of Rhodococcus ruber. Applied Microbiology and Biotechnology 65 (1): 97–104. doi: 10.1007/s00253-004-1584-8.
73. Yamada-Onodera K, Mukumoto H, Katsuyaya Y et al. (2001) Degradation of polyethylene by a fungus, Penicillium simplicissimum YK. Polymer Degradation and Stability 72 (2): 323–327. doi: 10.1016/S0141-3910(01)00027-1.
74. Pometto AL, Lee B, Johnson KE (1992) Productin of an extracellular polyethylene-degrading enzyme(s) by Streptomyces species. Applied nd Environmental Microbiology 58 (2): 731–733. doi: 10.1128/aem.58.2.731-733.1992.
75. Ghosh SK, Pal S, Ray S (2013) Study of microbes having potentiality for biodegradation of plastics. Environmental Science and Pollution Research 20 (7): 4339–4355. doi: 10.1007/s11356-013-1706-x.
76. Oda Y, Oida N, Urakami T, Tonomura K (1997) olycaprolactone depolymerase producedby the bacterium Alcaligenes faecalis. FEMS Microbiology Letters, 152 (2): 339–343. doi: 10.1016/S0378-1097(97)00222-X.
77. Kim DY, Rhee YH (2003) Biodegradation of microbial and synthetic polyesters by fungi. Applied Microbiology and Biotechnology 61 (4): 300–308. doi: 10.1007/s00253-002-1205-3.
78. Tomita K, Kuroki Y, Nagai K (1999) Isolation o thermophiles degrading poly(l-lactic acid) Journal of Bioscience and Bioenginering, 87(6), 752–755. doi: doi: 10.1016/S1389-1723(99)80148-0.
79. Nakajia-Kambe T, Shigeno-Akutsu Y, Nomura N et al. (1999) Microbial degradation of polyurethane, polyester olyurethanes and polyether polyurethaes. Applied Microbiology and Biotechnlogy 51 (2): 134–140. doi: 10.1007/s002530051373.
80. Howard GT, Ruiz C, Hilliard NP (1999) Growth of Pseudomonas chlororaphis on apolyester–polyurethane and the purification andcharacterization of a polyurethanase–esterase enzyme. International Biodeterioration & Biodegradation 43 (1): 7–12. doi: doi: 10.1016/S0964-8305(98)00057-2.
81. Danko AS, Luo M, Bagwell CE et al. (2004) Involvement of linear plasmids in aerobic biodegradation of vinyl chloride. Applied and Environmental Microbiology, 70(10), 6092–6097. doi: 10.1128/AEM.70.10.6092-6097.2004.
82. Mor R, Sivan A (2008) Biofilm formation and partial biodegradation of polystyrene by the actinomcete Rhodococcus ruber. Biodegraation 19 (6): 851–858. doi: 10.1007/s10532-008-9188-0.
83. Auta HS, Emenike CU, Fauziah SH (2017) Screening of Bacillus strains isolated from mangrove ecosystems in Peninsular Malaysia for microplastic degradation. Environmental Pollution (Barking, Essex: 1987), 231(Pt 2), 1552–1559. doi: 10.1016/j.envpol.2017.09.043.
84. Gong J, Kong T, Li Y et al. (2018) Biodegradation of microplastic derived from poly(ethylene terephthalate) with bacterial whole-cell biocatalysts. Polymers 10 (12). doi: 10.3390/polym10121326.
85. Liu J, Xu G, Dong W et al. (2018) Biodegradation of diethyl terephthalate and polyethylene terephthalate by a novel identified degrader Delftia sp. WL-3 and its proposed metabolic pathway. Letters in Applied Microbiology 67 (3): 254–261. doi: 10.1111/lam.13014.
86. Bianco A, Sordello F, Ehn M et al. (2020) Degradation of nano plastics in the environment: Reactivity and impact on atmospheric and surface waters. Science of the Total Environment 742: 14413. doi: 10.1016/j.scitotenv.2020.140413.
87. Zurier HS, Goddard JM (2021) Biodegradation of microplastics in food and agriculture. Current Opinion in Food Science 37: 37–44. doi: 10.1016/j.cofs.2020.09.001.
88. Zhang J, Gao D, Li Q et al. (2020) Biodegradation of polyethylene microplastic particles by the fungus Aspergillus flavus from the guts of wax moth Galleria mellonella. Science of the Total Environment 704: 1–8. doi: 10.1016/j.scitotenv.2019.13593