



Plastics, Bioplastics and Water Pollution [†]

Ioanna Damikouka * and Olga Georgiadou

Department of Public Health Policy, School of Public Health, University of West Attica, 196 Alexandras Avenue, 115 21 Athens, Greece; olga.georgiadou1965@gmail.com

* Correspondence: idamikouka@uniwa.gr

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Abstract: Microplastics are a ubiquitous environmental pollutant that can potentially pose a threat to both aquatic organisms and to human health. Prevention methods are pivotal to microplastic mitigation, and new trends are emerging, that include a growing industry of alternative materials. Bioplastics and biodegradable products are emerging as a possible solution to mitigate pollution from petroleum-based single-use and limited-use items. The paper presents findings on the occurrence of plastics and microplastics in aquatic systems, on the composition and biodegradability of bioplastics, and on the potential of bioplastics to provide a solution to plastic pollution.

Keywords: microplastics; bioplastics; biodegradable plastics; pollution; sediments; water pollution

1. Introduction

The production of plastics is predicted to continue increasing in line with the increase in the world population [1,2]. An estimated 8300 million metric tons of plastics have been produced to date, of which 6300 million tons have been classified as waste [3]. In 2021 alone, annual global production exceeded 390 million tons [4]. As a consequence of improper waste disposal, plastics enter freshwater and marine environments primarily through runoff and disposal on land, and while efforts are ongoing to reduce plastic waste entering the environment, it is impossible to remove most of the existing plastic; much of it will remain for decades, if not centuries. In the aquatic environment natural forces such as wave action and weathering can induce plastic breakdown into microplastic fragments (<5 mm). These can be further degraded into smaller particles, such as nanoplastics (<100 nm) [5]. Sewage disposal, either raw or after treatment, can also contribute to the environmental microplastic burden. Microplastic removal efficiency following wastewater treatment has been found to range from 72% to 99.4% [6]. While retained microplastics are concentrated in sludge, unretained fragments are released with waste effluent into the water environment. Sediment contamination is now also widespread, and microplastics have been identified even in deep oceanic environments, including the Habal sediments of the Mariana Trench [7]. Consequently, microplastics are now considered a ubiquitous environmental pollutant worldwide.

Microplastics and nanoplastics can be ingested and accumulated in aquatic organisms with numerous reported consequences [8]. Over 900 species have been affected through ingestion or entanglement [9]. Fibers and particles (800–1600 µm) are the most common form of microplastics reported from the field [10] in organisms such as mussels, oysters and fish. Transfer through the food chain can result in human exposure [11].

New trends are encouraging a growing industry of alternative materials, the so-called bioplastics where ‘a plastic material is defined as a bioplastic if it is either bio-based, biodegradable, or features both properties’ [12]. Compounds such as biobased polypropylene and polylactic acid can be made from renewable resources, thus saving fossil fuels and reducing carbon dioxide emissions. Theoretically, such biomaterials reduce the plastic life cycle and mitigate



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plastic pollution in the environment [13]. The biodegradation of bioplastics has gained particular interest as a sustainable solution and makes the need for the production and use of biodegradable plastics necessary.

This paper provides insights into the occurrence of plastics and microplastics in the aquatic environment, the composition and biodegradability of bioplastics, possible strategies for plastic and bioplastic waste management and the potential of bioplastics to provide a solution to plastic pollution.

2. Plastics and Microplastics in the Freshwater Environment

Studies on microplastics in freshwater environments are progressing rapidly, with microplastic particles found in a range of freshwater environments worldwide, including surface waters like lakes and rivers, but even groundwater [14,15]. Water surface, depth, wind, currents, and particle density determine the transport and fate of particles within these aquatic systems [16]. Microplastics have been detected in drinking water resources, and even in drinking water [17]. The most commonly found polymer types that together account for around 70% of the plastic production worldwide [4], especially in aquatic environments, are polyethylene (high-density, low-density, linear low-density polyethylene), terephthalate, polypropylene, polystyrene, and polyvinyl chloride [2,18].

Rivers act as waterways for the transportation of microplastics from the terrestrial environment. Sediments are receptors of many pollutants from anthropogenic activities including metals [19] and organics, as well as plastics and microplastics. Freshwater sediments have received less attention in relation to marine sediments [20], and will therefore be the main focus of this review. Microplastic abundances ranging from tens to hundreds of particles/kg have been reported in river sediment, values that are generally comparable to those reported in marine sediment. For example, Ding et al. (2019) reported concentrations in Wei River, China, ranging from 360 to 1320 particles/kg of dry sediment [21]; Saad et al. (2022) reported an abundance ranging from 29.12 to 1095.89 particles/kg from the Vaal River, South Africa [22]; Horton et al. (2016) reported hundreds of particles/kg in river sediments of the River Thames, United Kingdom [23]. At higher concentrations, thousands of particles/kg have been reported in river sediments in Germany [20].

3. Bioplastics

Bioplastics are a family of different materials and can be classified into bio-based plastics and biodegradable plastics based on fossil resources, such as polybutylene adipate terephthalate (PBAT).

Bio-based plastics are made from biomass, e.g., corn, sugarcane, wood or organic waste and organic by-products such as cooking oil waste. However, not all bio-based plastics are biodegradable. Examples of bioplastics that are both bio-based and biodegradable are polylactic acid (PLA), polyhydroxyalkanoates (PHAs), polybutylene succinate (PBS), and starch plastics [12,24]. Appropriate plasticizers (e.g., low-molecular-weight citrates for PLA) can be applied to enhance the properties (e.g., flexibility, brittleness, hydrophilicity, poor moisture, thermal, and physical properties) of bio-based plastics [24].

4. Plastic and Bioplastics Waste Management

Appropriate management methods for conventional plastics based on the waste management hierarchy of the Waste Framework Directive [25], in order of priority, are prevention of plastic waste production through source reduction, preparation for reuse, recycling, recovery through incineration, and finally, plastic waste disposal usually in sanitary landfill. However, guidelines are not implemented fully and mismanagement of plastic waste on land is a major source of plastics in the oceans [26].

Source reduction strategies include the redesigning of packaging with lighter materials and innovative materials to make recycling easier. Additionally, European legislation imposes a ban on certain single-use plastics [27] for the mitigation of plastic pollution.

Despite the significance of prevention of use and source reduction, policies, and their implementation vary to a great extent globally.

Recycling strategies cover the conversion of plastic waste to new products, providing significant potential for the conservation of both raw materials and energy. However, unlike glass and metal, the recycling of plastic poses technical difficulties in mechanical and chemical (pyrolysis, gasification etc.) processes due to the complexity of plastic materials (multi-layer products, additives, phthalates, brominated flame retardants, etc.), limitations in polymer recycling such as their aging or degradation and the incompatibility of resins [28–31]. Policies and the ease of implementation for end-users again vary significantly.

While the incineration of plastic waste can lead to a recovery of energy, sanitary landfill is employed when plastic waste cannot be used to produce new raw materials or energy, and is considered as the final destination of plastic waste. Post-consumer plastic waste treatment in Europe in 2020 has shown great variation in treatment between member countries, from 21% (for Finland) to 45% (for The Netherlands) recycling rates, from 0% (The Netherlands) to 75% (for Malta) landfilling rates, and from 2% (Greece) to 77% (for Finland) energy recovery rates [4].

As bioplastic technology advances, emphasis is put on the ease of biodegradability and appropriate disposal. Biodegradability is affected by the physical and chemical structure of bioplastics, as well as the environmental conditions [32]. Biodegradable bio-based plastics can be treated together with other organic waste in industrial compost facilities or anaerobic digestion units, diverting them from landfills and turning them into either compost or biogas, respectively. However, technologies for the isolation of biodegradable plastics [33] or an appropriate waste collection system at source are needed for the separation of non-biodegradable from biodegradable bioplastics, and other plastics. When bioplastics are disposed of inappropriately, degradation may not occur efficiently since specific environmental conditions are required [34]. Standard specification tests such as ASTM D6400-21 have been developed [35] for the investigation of biodegradability and compostability of plastics under proper conditions within industrial and municipal composting facilities. In the natural environments, however, current monitoring and assessment methods are inadequate to prognosticate bioplastic degradability [13].

5. Conclusions

Bio-based and biodegradable bioplastics made from renewable biomass are a promising alternative to conventional plastics, with great potential to be developed for everyday use. While the biodegradability of bioplastics affects their sustainability and utility, such products have significant environmental advantages. The gradual replacement of conventional plastics with bioplastics will reduce the carbon footprint and greenhouse gas emissions of materials, while an appropriate waste collection system at source and proper recycling and disposal methods of bioplastics will help mitigate plastic and microplastic pollution.

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