The Role Of Bacteria In Microplastic Bioremediation And Implications For Marine Ecosystems

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Abstract. Microplastics are micro particles <5 mm in size that pose a threat to the survival of organisms living on land and in the ocean. Microplastics contain toxic and carcinogenic or persistent chemicals that will directly or indirectly have a negative impact on marine ecosystems. The process of decomposing waste into microplastics takes a very long time that can take hundreds of years. This can be overcome by the use of bacteria using bioremediation techniques to degrade microplastics in the marine ecosystem. With regard to this, this article aims to review the role of bacteria in degrading microplastics and their impact on marine ecosystems. The method used in this article is a literature review by reviewing related and relevant articles as references. The articles obtained will be sorted according to the topic of the role of bacteria in microplastic bioremediation. Furthermore, it will be analyzed and the results used as a reference for the preparation of this article. The results of the review that the author found were that Pseudomonas, Ochrobactrum, Halomonas sp and Clostridium botulinum bacteria were able to become agents of microplastic degradation in the marine ecosystem

1 Introduction

One of the most important ecosystems in the world is the marine ecosystem, which is also referred to as the marine ecosystem, consisting of deep water ecosystems, shallow sand beach or bitorol ecosystems, and tidal ecosystems [1]. Indonesia is a country with a larger water area than land. Plastic is a type of waste that is very difficult to decompose in soil and takes hundreds of years to decompose.

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Plastic has many benefits but can be very dangerous if not used properly, especially in everyday life [2]. Most of the plastic waste that pollutes rivers eventually enters the ocean [3]. Plastic is now considered a major threat to the marine environment as it has increased significantly worldwide over the past sixty years [4].

According to [5], plastic waste that is usually only used once has become a challenge for the environment as a whole. Microplastics are formed from plastic waste that decomposes in nature. More than 80% of microplastic pollution in the environment comes from urban dust, tires, and textiles [6]. Microplastics are small particles less than 5 mm in size that threaten the survival of living things on land and in the ocean. Microplastics can be primary or secondary microplastics. Primary microplastics are made to a smaller size. They come from microbeads, plastic pellets, and synthetic textiles in personal care products. Secondary microplastics come from larger plastic debris that eventually become brittle and cut into smaller pieces [7]. Microplastics are made from various polymers, such as PE (polyethylene), PP (polypropylene), PS (polystyrene), PVC (polyvinyl chloride), and PET (polyethylene terephthalate). Microplastics are also found in various forms such as foam, fragments, fibers, films, and spheres [8].

Because plastics can last a long time they often contain chemicals that are potentially toxic and carcinogenic. Microplastics are a problem in the environment. If organisms eat them, it will have an impact on aquatic life. In addition, plastic waste damages marine life and coral reefs and disrupts the balance of marine ecosystems. If microplastics collect in organisms and are then passed on to humans through the food chain, it can also affect humans. This can result in human diseases [9]. Seafood consumed by humans, such as fish and shellfish (molecular species, crustaceans and echinoderms) can negatively impact human health.

Bioremediation technology method is one of the attractive approaches to control microplastic pollution [10]. Utilizing the ability of living things to reduce or decompose microplastics by using compounds released by bacteria is known as bioremediation [11]. Bacteria are a group of prokaryotic microorganisms with single cells that live in groups and have a nuclear envelope that allows them to live in various places [12]. Bacteria have many benefits and negative effects in life [13]. Most studies show that plastic polymer-degrading microorganisms are dispersed and grow in different types of ecosystems. *Bacillus megaterium*, *Pseudomonas* sp., *Halomonas* sp., and *Azotobacter* bacteria are found in mangrove water and have the ability to destroy microplastic polymers [14].

The author wrote this article to find out and identify the role of bacteria in degrading microplastics that have an impact on marine ecosystems. This is done because microplastics have negative effects on marine ecosystems and the purpose of this article is to review several articles that discuss the role of bacteria as bioremediation agents for microplastics that impact marine ecosystems.

2 Research Method

The author employed descriptive research methods by utilizing several articles as literature to develop the content of this paper. This method involved a comprehensive review of relevant articles. The process of preparing this literature review began with searching for articles from both national and international journals that were relevant to the article's title. Each article's content was then carefully reviewed, and the results of these analyses were used as references during the writing process. Ultimately, the findings from the analysis of these articles were compiled into a comprehensive literature review.

3 Result and Discussion

Carpenter and Smith first discovered and reported microplastics in the early 1970s [15]. Microplastics are small particles less than 5 millimeters in diameter that are commonly found in seawater according to [16]. In addition, plastic particles can be considered microplastics if they are between 0.3 mm and 5 mm in size [17]. Scientists around the world and Indonesian scientists have conducted many studies on the presence of microplastics. China, Japan and Spain have microplastics. One of the biggest plastic waste generators in the world is Indonesia. Coastal areas such as beaches have a lot of microplastics [18]. According to [19] stated that microplastics are not only found in sediments and seawater, but also in marine biota species. According to research by [20] microplastics are very much found in marine ecosystems, especially in coastal areas around the world in both sediment and water. Ninety percent of microplastic waste is found in surface seawater [3] and the remaining part is found in sediments.

There are several types of microplastics found in sediments and water: fragments, fibers, fibers, films, and pellets [21]. Microplastic fragments are plastic fragments (Mochamad Rudyansyah Ismail et al., 2014). Microplastic fibers have the form of fibers or fibers that easily accumulate in sediments. Film microplastics are sheet-shaped, and primary microplastics are pellets derived from industrial plastic materials made [18].

Microplastics come in two categories. If they enter the body of an organism, both are harmful. Primary microplastics are plastic particles that directly enter the environment in the form of small particles. These particles come from a wide variety of products that contain plastic, such as shower gels and the crushing process of large plastic objects when they are made or used [3]. [22] states that primary microplastics are pure plastic particles that enter marine areas due to negligence in the production process. However, according to [23] industries make primary microplastics for specific products such as cosmetics, toothpaste, soap and detergents.

Secondary microplastics are small plastic pieces made from larger plastic debris that become smaller both on land and in the sea. [Primary or secondary microplastics can be found in cosmetics and facial cleansers that directly enter the environment [24]. The presence of microplastics in the environment raises concerns that they will be consumed by living things due to their small size [25]. As a result of their widespread and bioavailable nature microplastics can be eaten by marine organisms [26]. Microplastics have been found in the digestion of amphipods, sandworms, barnacles [27], clams [28], crustaceans [29], seabirds [30], and fish [31].

To control microplastic pollution, bioremediation techniques [10];[32];[33] can utilize native bacteria or microbes that can grow in media exposed to controlled microplastics. The process called "bioremediation" involves the biological decomposition or reduction of hazardous organic and inorganic wastes to prevent polluting compounds. These wastes are converted into other non- or less harmful compounds such as carbon dioxide and some other gases. Utilizing the ability of living things to reduce or decompose microplastics by using compounds secreted by bacteria is known as bioremediation [11].

Bacteria are a group of prokaryotic microorganisms with single cells that live in groups and have a nuclear envelope that allows them to live in various places [12]. Bacteria have many benefits and negative effects in life [13]. Bioremediation is a method that is more environmentally friendly than other methods [34]. According to the United States Environmental Protection Agency (EPA), bioremediation agents are cultures of microorganisms, enzymes, or nutrient stimulants that can increase the rate of biodegradation. Due to the high capacity of contaminants to be degraded into harmless or less harmful compounds the use of microorganisms is considered more effective [35]

One of the main methods for bioremediation of organic compounds is degradation by microbes. How microorganisms can be degraded and transformed depends on how long the bioremediation process takes. Bioremediation is unique in that it can reduce pollutants or remove contaminants from the natural environment by using native microbial communities present in nature. Indigenous bacteria that come from self-isolation from the natural medium to be decomposed are called indigenous bacteria [36]. They function by producing enzymes that can bind elements to the decomposed media. Indigenous bacteria provide many benefits in various aspects of human life.

Indigenous bacteria are bacteria that can live in nature and are usually native to a particular region. Native bacteria reduce pollution in several ways [37]. Native bacteria are excellent as bioremediation agents in sewage treatment [38]. This is because their fiber-degrading bacteria are highly resistant to contaminants such as heavy metals, oil spills, and microplastics. With the help of various enzymes, bacteria utilize contaminants as carbon and nutrients during their metabolic process. Many studies have been conducted on the microbial breakdown of synthetic polymers such as plastics viz

Table 1. Types of degrading bacteria

No	Types of degrading bacteria	Plastic Synthesis Polymers	Source
1	Brevibacillus borstelensis	Polyethylene	[39]
2	Alcaligenes faecalis	Polyhydroxyalkanoate (PHA),	[40]
3	Alcaligenes faecalis	Polycaprolactone (PCL)	[41]
4	Streptomyces sp.	Polyhydroxyalkanoate (PHA)	[42]
5	Streptomyces sp.	Polyhydroxyalkanoate (PHA)	[43]
6	Bacillus brevis	Olylactic acid (PLA)	[44]
7	Pseudomonas putida	Polyvinyl chloride (PVC)	[45]
8	Clostridium botulinum	Polycaprolactone (PCL)	[40]
9	Pseudomonas and Ochrobactrum	High density polyethylene (HDPE) and low density polyethylene (LDPE) plastic polymers	[46]
10	Bacillus megaterium, Pseudomonas sp, Halomonas sp, and Azotobacter	Microplastic polymers	[14]

Several environmental factors such as pH, temperature, weight, and molecular size of the substrate, affect the ability of microoganism enzymes to destroy microplastics. Some microorganisms including bacteria and fungi have the ability to destroy microplastics (Roohi et al., 2017). The following steps are used for polymer biodegradation [47]: 1. Microorganisms adhere to the plastic surface. If microorganisms adhere to or come into contact with the plastic surface, a biofilm will form. 2. Assimilation makes the degraded polymer a source of energy and food for the growth of microorganisms; 3. Degradation of the polymer, which occurs through fragmentation through hydrolysis; and 4. Final disintegration of the polymer, which occurs through mineralization.

Ochrobactrum bacteria belong to the subclass Alphaproteobacteria. Bacteria of this genus are found phylogenetically using the structure of nitrogenous bases in DNA, namely rRNA and 16S rDNA. Bacteria of the genus Brucella are close to this genus based on their genetic characteristics. The majority of this genus have the following characteristics: they are aerobic, generally motile because they have peritrichous flagella as a means of locomotion, they are gram-negative bacteria with cell shapes such as bacilli or rods, and they are bacteria that are unable to break down glucose for the fermentation process (non-fermentative bacteria).

Gram-negative *Pseudomonas* bacteria are one of the hydrocarbonoclastic bacteria that have the ability to destroy various types of hydrocarbons [48]. Some studies have also found that this type of bacteria has the ability to destroy various polymers, both synthetic and natural polymers. According to research conducted by [46], the bacteria *Pseudomonas* sp. and *Ochrobactrum* sp. are considered to have the ability to destroy microplastics made of high density polyethylene (HDPE) and low density polyethylene (LDPE).

Research conducted by [49] *Halomonas* sp. bacteria isolated from polypropylene plastic from seawater aims to obtain potential bacteria capable of degrading polypropylene plastic so that it has the potential to degrade synthetic plastics. Isolates were inoculated into mineral media with the addition of sterile polypropylene synthetic plastic film. Bacteria of the genus *Halomonas* sp. as a degrading agent of nonmedical mask waste made from polypropylene were found at Tanjung Pasir Beach. These *Pseudomonas* sp. bacteria have an inducible operon system that produces specific enzymes to metabolize carbon sources that are not commonly used. Therefore, these bacteria play an important role in the biodegradation of various polymers, including xenobiotic chemicals and pesticides.

Clostridium botulinum bacteria are gram-positive, rod-shaped, non-motile, obligate anaerobes that produce spores. One type of plastic waste that can be degraded by *Clostridium* under anaerobic conditions is PCL, or polycaprolactone, which is a synthetic polyester that is easily degraded by *Clostridium botulinum* bacteria [40].

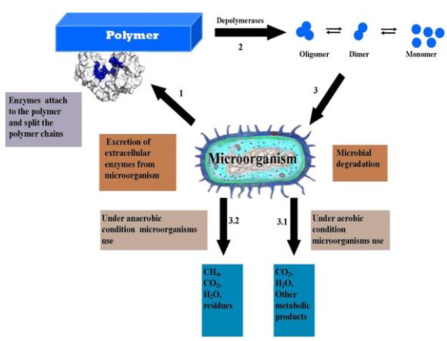

Fig. 1 Mechanism of plastic biodegradation by bacteria [43]

Based on Figure 1, it can be seen that there are three main mechanisms of polymer biodegradation by bacterial enzymes. First, the extracellular enzymes of bacterial isolates adhere to the polymer, stop hydrolytic cleavage, and then the complex polymer chain is broken down into shorter chains such as oligomers, dimers, and monomers. The shorter polymer chains pass through the semi-permeable membrane of the bacteria and are then broken down by extracellular enzymes.

Physical or Chemical Changes in Polymers caused by environmental factors such as light, heat, chemical conditions, or biological activity are called degradation. In contrast, according to [50] biodegradation is a degradation process in which chemical compounds are created by microorganisms especially bacteria. The biodegradation process allows aerobic and anaerobic separation of organic matter. Synthesized plastics can be naturally degraded by several microorganisms such as bacteria, fungi, and actinomycetes. In general, several different microorganisms are required to cut polymer chains into monomers. A bacterium has the ability to break down the polymer into monomers, while another bacterium has the ability to utilize the monomers and produce simpler compounds.

In most cases the degradation results in changes to the polymer properties such as polymer bond cleavage, transformation, or formation of new chemical structure bonds. There are two different ways in which polymers can be degraded: aerobic produces carbon dioxide and water, while anaerobic produces carbon dioxide, water, and methane. Due to the lack of water and long polymer molecules, microorganisms cannot incorporate the polymer directly into the cell in this process. Intracellular and extracellular depomerase enzymes actively participate in the process of polymer degradation in biology. Bacteria secrete extracellular enzymes, which allow the polymer to be depolymerized outside the cell [51].

3.1 Impact of Microplastic Pollution

Microplastics are a problem for polluted environments. It negatively affects the survival of marine creatures and people who consume seafood. Some of the negative effects of microplastics are as follows:

a. Effects on the Environment. The unwitting use of plastic packaging and other plastic materials has led to the accumulation of plastic waste. With its high durability, plastic may cause environmental problems. Plastics can be contaminated both on land and in the sea if these products are not disposed of properly and there is no good waste management [52]. Human health, economy, tourism and coastal aesthetics are some of the effects of microplastic pollution. Microplastics can pose a greater threat to lower trophic level marine organisms such as plankton that consume microplastics as filter feeders, and impact higher trophic level organisms through bioaccumulation.

b. Effects of Microplastics on Aquatic Biota. Microplastics ingested by aquatic biota can affect the biota physically because they contain toxic substances. Microplastics can be ingested by aquatic biota because they are similar in size to plankton organisms [53]. If microplastics enter the body of biota, it can damage the digestive tract, reduce growth rates, stop enzyme production, lower steroid hormone levels, disrupt reproduction, and cause exposure to harmful addictive plastics [54]. The size of the debris affects how plastic contamination affects marine life. Small plastic debris, such as fishing nets and threads, can disrupt organ function systems.

   Aquatic life can ingest smaller plastic debris, such as pellets, bottle caps and matches. This can lead to intestinal blockages and chemical poisoning. However, small organisms in the habitat may ingest microplastics that can have negative impacts. Benthic (in deep and open waters) and pelagic (in near-surface waters) organisms are some of the marine animals that ingest microplastics in various ways and order levels. Benthic marine invertebrates ingest microplastics, such as sea cucumbers, clams and lobsters. Some invertebrates ingest even more plastic fragments than others; sea cucumbers in benthic habitats ingest disproportionate amounts of plastic fragments based on the ratio of plastic to sand [55].

c. Human Impact Microplastics can also affect humans if they collect in animals and then enter humans through the food chain. This can result in human diseases [9].

Seafood often consumed by humans, such as fish and shellfish (molecular species, crustaceans and echinoderms) can negatively impact human health. This seems to apply to filter-feeding biota, such as oysters and mussels in Europe, but could also apply to sea cucumber biota that is more widely used in Asian cuisine [17,56] due to the point at which microplastics can enter the human body.

Microplastics contain many harmful compounds such as polychlorinated biphenyls (pcbs), metals, and polybrominated diphenyl ethers (pbdes). These compounds can be harmful if accumulated in the human body. According to the study, experts from the Federal Environmental Agency conducted a laboratory analysis of the ten most common plastics in the world. An average microplastic concentration of 20 microplastic particles per 10 grams of feces was found in eight volunteers.

4 Conclusion

One of the most important ecosystems in the world is the marine ecosystem, which is also referred to as the marine ecosystem, consisting of deep water ecosystems, shallow sand beach or bitorol ecosystems, and tidal ecosystems. Indonesia is a country with a larger water area than land. Microplastics are small particles less than 5 mm in size that threaten the survival of living things on land and in the ocean. Microplastics are made from various polymers, such as PE (polyethylene), PP (polypropylene), PS (polystyrene), PVC (polyvinyl chloride), and PET (polyethylene terephthalate). Bioremediation technology method is one of the attractive approaches to control microplastic pollution. Utilizing the ability of living things to reduce or decompose microplastics by using compounds released by bacteria is known as bioremediation. Bacteria are a group of prokaryotic microorganisms with single cells that live in groups and have a nuclear envelope that allows them to live in various places. The results of the review that the author found were that *Pseudomonas* sp, *Ochrobactrum* sp, *Halomonas* sp, *Clostridium botulinum* bacteria were able to become agents of microplastic degradation in the marine ecosystem. There are three main mechanisms of polymer biodegradation by bacterial enzymes. First, the extracellular enzymes of bacterial isolates adhere to the polymer, stop hydrolytic cleavage, and then the complex polymer chain is broken down into shorter chains such as oligomers, dimers, and monomers. The shorter polymer chains pass through the semi-permeable membrane of the bacteria and are then broken down by extracellular enzymes. Microplastics are a problem for polluted environments. It negatively affects the survival of marine creatures and people who consume seafood. Some of the negative effects of microplastics are as follows: Effects on the Environment, Effects of Microplastics on Aquatic Biota, Human Impact.

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