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LITERATURE REVIEW Open Access

MICROPLASTIC POLLUTION IN GREEN SHELLS IN AQUATIC ECOSYSTEMS: A LITERATURE REVIEW OF DETERMINANT FACTORS AND MANAGEMENT

Globila Nurika[1], Hilda Nur Abidah[1], Edza Aria Wikurendra[2,3], Farida Wahyu Ningtyias[1]

[1]Department of Public Health, Faculty of Public Health, Universitas Jember, Jember 68121, Indonesia
[2]Doctoral School of Management and Organizational Science, Faculty of Economic Science, Hungarian University of Agriculture and Life Science, Kaposvar 7400, Hungary
[3]Department of Public Health, Faculty of Health, Universitas Nahdlatul Ulama Surabaya, Surabaya 60237, Indonesia

Corresponding Author:
*) nurikaglobila@unej.ac.id

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Abstract

Introduction: *Water territories produce a large number of biota worldwide. The imbalance in conserving aquatic ecosystems, along with the increasing disposal of waste into the environment, has resulted in the risk of contamination of the environment and the resulting biota. The dangers of waste disposal into water can destroy the ecosystem and affect the usability of water for the environment and human beings.* ***Discussion:*** *The PRISMA method was used in this literature review, which examined 35 articles: 23 articles from ScienceDirect, 10 articles from Proquest, and 2 articles from PubMed. Data were analyzed by synthesizing the research variables compared with theory and then presented in the form of tables and figures. The results of this study are presented with a complete narrative description of three sub-discussions, which consisted of the characteristics of microplastics in green mussels (color, shape, size, and abundance). The color was acquired in the dark, with the predominant form of fibers <1 mm in size, which determined the amount of microplastics in green mussels induced by both human and industrial activities, as well as countermeasures through filtration of industrial effluents, the utilization of organic plastics, and policy enforcement.* ***Conclusion:*** *Microplastics found in green mussels in Asian waters vary in their characteristics, with the main determinants of human and industrial activities as well as multi-sectoral countermeasures.*

INTRODUCTION

In addition to contaminating the environment, marine debris can also adversely affect ecosystems. Marine litter flows from rivers, lakes, and land into oceans. However, the major contributor to the existence of land-based waste is from humans who dispose of it inadvertently, and thus it enters the waterways that lead to the vast oceans (1). The increase in plastic waste is in line with the increase in population and usage. The exaggeration in the use of plastics, with a wide range of applications in the packaging industry, construction, automotive, medical, electronic, and other production products in the world, has reached 322 million tons (1). Plastics have non-degradable characteristics and, therefore, are the most significant contributors to the destruction of nature (2). The degraded plastic waste eventually decomposes into small pieces, which are not observable by the naked eye; this is known as microplastics. The increase in plastic production is increasing rapidly every year, and it is predicted that by 2050, the amount will reach 31.5 thousand million tonnes. As much as 79% of the plastic is discarded into the environment. Plastics do not simply dissolve but become small pieces.

Microplastics are ≤ 5 mm in size and can be divided into primary and secondary microplastics. Primary microplastics are micro-sized plastics that are deliberately produced, for example, in beauty products. Secondary microplastics are plastics that are initially large in size and undergo fragmentation to become smaller (3). The distribution of microplastics is determined by environmental factors such as wind, currents, tides, and

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hydrodynamics of the water (4). Microplastics may be incorporated into or consumed by marine biota. The chemical content of ingested microplastics is absorbed into the organs of marine biota and, subsequently, when consumed by humans, there is a toxigenic interchange inside the human organ (5). Mussels are one of the biota that are highly contaminated with microplastics. One example of a filter feeder organism is the mussel, which consumes the surrounding environment including water and sediment (6). Such a pattern of feeding may lead to the incorporation of various types of contaminants, particularly microplastics, into the mussel's body. Microplastics found on the deep seafloor were four times the amount observed on the surface and caused mussel biota with habitats on the distant seafloor to be more susceptible to contamination. Microplastics have been proven to disrupt fecundity (reproduction), feeding capacity, impaired digestion, and fecal excretion. Over a long period of time, it can produce smaller eggs and a decreased hatching rate (7).

Based on this research, several countries in Asia are conducting waste disposal and treatment incorrectly. Approximately 35% of them frequently dispose of waste in the water. Indonesia ranks second in Asia, followed by the Philippines, Vietnam, Thailand, Malaysia, and Myanmar. The average is nearly entirely found in Southeast Asia (8). Countries with extensive territorial waters are likely to have tourism potential. One of the aspects that influences marine tourism is considered to have an excellent qualification, which comprises the quality of the environment that is both clean and litter-free. However, the current condition is that several marine tourism sites are filled with trash, especially plastic waste. Data from the environmental program indicate that in 2017, as much as 70% of the world's oceans were affected by pollution, which threatens not only natural preservation but also the degree of public health and other health issues (9). Based on our literature review, we discovered that plastic fibers have already been found in Columbia, England, and even in the United States.

Beach is a tourist destination that is commonly visited by the public as a marine tourism destination and employment. However, this situation is a drawback as it lacks a proper balance in protecting the environment with the number of visits and appropriate utilization. With an increasing number of visitors, the existence of waste generation in coastal areas also increases because the level of use of environmental potential is greater by visitors than its carrying capacity (10). This is because waste processing in coastal areas experiences several problems, including the unavailability of adequate waste disposal facilities, the lack of support systems from the local government, and the attitude of the community due to the lack of good cooperation between them. The ocean serves as an ideal environment for the disposal of generated waste. The detectable pollutions such as plastic litter accumulations present on beaches are both arduous and time-consuming to clean up, which can impact huge detrimental to the health of marine life in these areas. Marine biota ecosystems are also threatened by pollution, physical habitat degradation, and over-exploitation of natural resources (11). Sources of coastal water pollution also include industrial waste, sewage, urban stormwater, shipping, agriculture, and aquaculture (12).

Mussel is a marine product that is used for consumption and snack business by coastal residents. The quality of life of mussels is threatened if beaches continue to produce waste without handling or processing. The clams eventually perish because they are no longer able to reproduce properly (11). Consumed shellfish, unknowingly contaminated with pollutants, may affect human well-being if exposed for long periods of time due to the transfer of toxicants from mussels to humans. It worsens if the shellfish consumed also undergoes a cooking process that is exposed to plastic cooking products. This can contribute to the mixing of microplastic contaminants into finished food. Because of their extremely small size, microplastics can be easily swallowed by marine biota and potentially have a negative impact if they accumulate in the human body or other biota through the food chain. Microplastics can be considered pathogen vectors because of their potential as microbial carriers. The minuscule size of microplastics also enables their transport to other organ tissues. Microplastics may enter the circulatory system from the intestines and lungs, and then accumulate in the intestines, liver, and kidneys. It can lead to various diseases, such as microplastics inhibiting mitochondrial depolarization pumps and depolarization, inducing reactive oxygen species (ROS), and affecting brain signalling mechanisms leading to fibrosis, autophagy, and even DNA mutations (13). From this description, this literature review identifies the abundance of microplastics in green mussels in coastal areas so that the determinant factors and countermeasures can be obtained.

DISCUSSION

This literature review used the PRISMA method to select scientific articles to answer research questions regarding the abundance of microplastics in green mussels in coastal areas. Articles were searched from three databases including Science Direct, PubMed, and Proquest with the keywords abundance of green mussel microplastics, determinants of green mussel microplastics, and microplastic countermeasures. The inclusion criteria were as follows: (i) articles from peer-reviewed journals from original research on the abundance of green mussel microplastics on beaches, (ii) written in English and Indonesian, (iii) issues 2011-2022 (Figure 1), and (iv) full-text articles. After determining the suitability of the research variables, 35 articles were analyzed, consisting of 23 articles from ScienceDirect, 10 articles from Proquest, and 2 articles from PubMed. Data analysis was carried out by synthesizing and comparing the research variable data with theory, as presented in tables and descriptions.

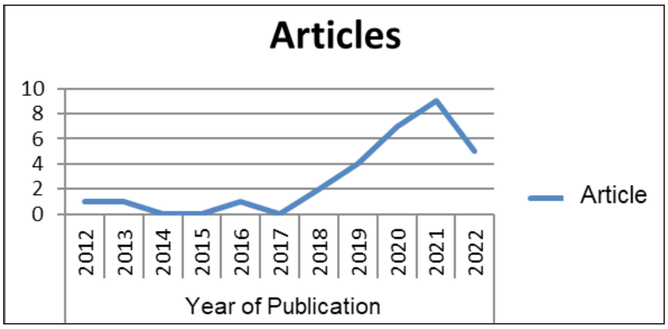

Figure 1. Year of Article Publication

Figure 2 shows a study of the geographic distribution of microplastic content in water. Two continents have been identified as research locations: Asia and Australia. Most research locations are in Asia, as it is the largest continent and has a wide water area. Thus, there will be more biota in the water area.

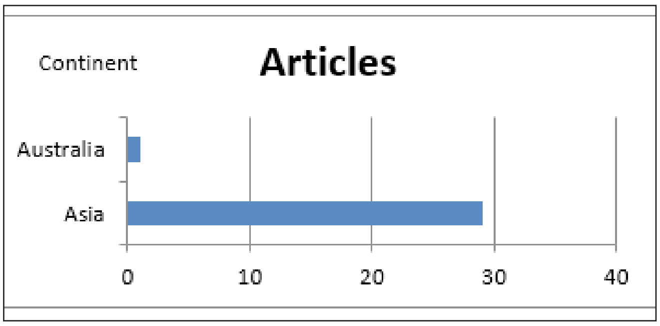

Figure 2. Geography of Study Area

The absence of a balance in protecting the aquatic environment with the biota it produces poses a risk of environmental pollution. The results of this study are presented in a narrative form, which describes three sub-discussions: the abundance of microplastics in green mussels, the determinants of the amount of microplastics in green mussels, and their management (Table 1).

Table 1. Distribution of Research Methodology from Review of 35 Articles

Research Method	Author's Name	Total Articles
Experimental study	G. Hariharan, R. Purvaja, I. Anandavelu , R.S. Robin, R. Ramesh (49); Xiaoyun Qu , Lei Su , Hengxiang Li , Mingzhong Liang, Huahng Shia (42); Doan Thi Oanh, Duong Thi Thuy, Nguyen Thi Nhu Huong, Hoang Thi Quyuh, Vu Thi Nguyet, Phuong Ngoc Nam, Pham Quoc Tuan, Ngo Thi Xuan Thnh, Bui Huyen Thuong, Le Thi Phuong Quynh (21); Sinja Elena Risto,kan, Khoirunnisa Assidqi, Neviaty Putri Zamani, Daniel Appel, Myriam Perschke, Mareike Huhn B, dan Mark Lenzo (50); Novianti Utami Rahmat, Khusnul Yaqin, Sri Wahyuni Rahim (51); S. WebbA, S. Gaw, ID Marsden, NK McRae (52); Nur Fadhilah *Rahim*, Khusnul Yaqin, Nita Rukminasari (53)	7
Observasional study	Liestiaty Fachruddin, Khusnul Yaqin, dan Reski Iin (54); Cristian Ryan Argamino and Jose Isagani B. Janairo (55); Naidu S.A. (56); I Fathonia dan MP Patria (57); Khoironi, S Anggoro dan Sudarno (58); ER Madeppungeng, MP Patria dan A Suryanda (59); Zakiyah Rahim, Neviaty Putri Zamani, Meutia Samira Ismet (15); Ramli, Khusnul Yaqin, Nita Rukminasari (60); Fitria Wulan Sari , Mimie Saputri , Devi Syafrianti, Dewi Andayani , M. Ali Sarong (39); Phoung Ngoc Nam, Pham Quoc Tuan, Duong Thi Thuy, Le Thi Phuong Quynh, Frederic Amiard (61); Quennie Morales Bilugan, Jomel S. Limbago , Redel L. Gutierrez (33); A R Putri, N P Zamani, D G Bengen (43); Nur Fadhilah Rahim, Khusnul Yaqin (62); Rajkumar L. Vasanthi a , Chinnasamy Arulvasu b , Ponnuchamy Kumar a , Pappu Srinivasan (63); Jamila Patterson, K. Immaculate Jeyasanta, R.L. Laju, J.K. Patterson Edward (64); Watcharee Ruairuen, Kittiya Chanhun, Wassana Chainate, Natenapa Ruangpanupan, Paphassara Thipbanpot and Naranun Khammanee (44); Jarukun Srikrajang & Taeng On Prommi (65); Fuad Muhammad, Hadiyanto, and Abdurrafi Alwan (66); Nurul Atikah Mohd Amin (67); Phaothep Cherdsukjai, Vararin Vongpanich, Pensiri Akkajit (68); Kaushik Dowaraha , Arunkumar Patchaiyappana,Chinnasamy Thirunavukkarasub , Shanmuganathan Jayakumara , Suja P. Devipriya (69); Mark Ariel Diamsim Malto, Antonino Baconawa Mendoza Jr. (70); Gita Natalia Taruk Linggi, Khusnul Yaqin, Basse Siang Parawansa, Liestiaty Fachruddin, Budiman Yunus and Sri Wahyuni Rahim (71); Wright, S.L., Thompson, R.C., Galloway (72); Von Moos, N., Burkhardt-Holm, P., Kohler, A. (73); Nicholson, S., Lam, P.K.S. (47)	26
FTIR method	Nur Atifah Mazlan, Lilian Lin and Heon E. Park (74); Ramdha Mawaddha1, Firdaus2, Akbar Tahir (75)	2

Characteristics of Microplastics in Green Mussels

Microplastics can appear in various forms in the environment, including in coastal areas. The shape of each microplastic particle depends on the original type of plastic before it is chopped (14). Based on a previous review, it was found that the form categories of microplastics comprise fibers, filaments, fragments, granules, films, flakes, fibers, and pellets (15). It is possible that the large number of microplastics in the form of fibers originates from fishermen's activities in the use of fishing gear, such as fishing rods or nets. Community activities such as washing clothes, some of which were still carried out on the beach, also contributed to the existence of microplastics in the form of fibers. Fibers are easy to find and spread in the ocean because they are the final disposal estuaries. Therefore, microplastic particles are often in the form of fibers (16). Fiber in the form of long fibers can be obtained from pieces of monofilament fishing nets/hooks, ropes and fabrics by synthesis (17). The form of fiber found in marine biota is due to the high fishing activity of biota, thus increasing the sediment concentration in the sea (18). This discovery was also the same as Davidson's research results, which stated that the type of microplastic that often dominates was fiber, such as that found in green mussel biota in Columbia, England (90%). The highest percentage of microplastics in the form of fibers was also found in the coastal areas of Singapore, at approximately 72% (19). Studies on microplastics in Indonesia and the United States have shown that only fiber types are found in oysters and mussels. Microplastics in shells were also found in Canada, and only one type, namely fiber (20). Microplastic particles in the form of fibers are easier for shellfish to digest (21).

Fragment types of microplastics originate from water bottles, plastic containers, and other plastic pieces. The fragments are solid synthetic polymer plastics. The distinction between filaments is their transparency, as filaments are typically transparent compared to fragments (22). Fragments are a particular form of microplastics that originate from rigid plastic waste, such as household appliances. The filaments were translucent sheets with flexible texture (23). Filaments are often found in scraps of packaging and plastic bags. Filaments are found on the surface of water because their density is lower than that of other forms, and they can be easily transported through water media (24). Granules are a form of microplastic that is often deliberately produced in micro-size to be used as food for biota in the waters (25). The granules are in the form of white granules with brown gradations and a dense texture measuring < 1 mm, which are often used for production in the industrial sector (25).

The color of microplastics can be used as a source to determine where the garbage in the sea originates or the condition of the microplastics themselves (26). Black and dark colors (brown, purple, and green) indicate that microplastics and other organic particles absorb high levels of contaminants and turn into pollutants (27). In 2012, Hidalgo found the existence of Polymerized Styrene (PS) and polypropylene (PP) types, which allegedly contain polycyclic aromatic hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs) that were adsorbed on black and dark microplastic particles. Blue is thought to originate from artificial dyes resulting from continuous human activities, such as industry (28). The results of the color of the microplastic particles based on their overall shape show that the blue color is in the form of a fiber. The microplastics, which are blue in colour, also come from synthetic dyes for the manufacture of plastics, such as those commonly used, called as copper phthalocyanines (29).

Microplastics are broadly classified based on their morphological characteristics, such as shape, color, and size. Size is an important factor because it is related to its effect on an organism. The greater the surface area, the greater the potential for microplastics to release chemicals. According to the EFSA Panel on Contaminants in the Food Chain, there is no standard definition for the size and composition of microplastics. However, it is generally considered that the particles are between 1 and 5 mm in size (30). An additional distinction was made between small (1 mm) microplastics and large (5 mm) microplastics. Recently, some researchers have defined microplastics as particles <1 mm in size to put them in the micrometer range. However, particles larger than 5 mm are considered mesoplastic (5–25 mm), macroplastic (>25 mm), and nanoplastic (<1 μm). These measurements were conducted in a previously researched environment. Fragmentation of macro-sized plastic into micro-sized plastic is due to ultraviolet radiation, mechanical forces from seawater waves, oxidative properties of plastic, and hydrolytic properties of seawater (30). Microplastic particles in green mussels (*Perna viridis*) are influenced by the age and size of the shell. Based on previous studies, small shells can absorb contaminant substrates including microplastics with a size of 0.15-3 mm up to a size of up to 5 mm in size (31). A previous study also discovered that the size of microplastics in mussels range from 0.25 to 4.5 mm, which signifies that small mussels can only digest microplastics that are relatively small and vice versa (32).

When microplastics are transmitted to marine waters, they can pollute the biota and cause problems for the viability of marine biota that are used as food by humans. Marine biota inhabiting waters polluted by microplastics can accumulate in their body tissues (33). Microplastics are often called fragments of degraded plastics, have a particle size of <5 mm, and can accumulate in high amounts in seawater and sediments. Because of their small size and high bioavailability to aquatic organisms, microplastics are widely dispersed throughout the ocean. This poses a risk, as microplastics can easily be consumed by marine biota (32). Many microplastics have been detected in fresh water, sediment, soil, atmosphere, seawater, beach sand, and are scattered in polar regions and the Tibetan Plateau (34). Microplastics can accumulate in a variety of aquatic and terrestrial organisms as well as in plants (35). In conclusion, microplastics have extensive implications for Earth's ecosystems. Microplastics are also found in filter-feeding organisms, in addition to being detected within fish. in the coastal areas of China, microplastic contaminants are often found in the green mussel biota. Bivalves of the Mytilus endulis species, both caught directly on the beach and cultivated, are proven to contain microplastics in varying amounts, such as 0.9-4.6 grains/g and 1.5-7.6 grains/g individuals (36). This research is in line with research conducted on 18 shellfish collected from Brazilian waters, which showed the presence of microplastics in the shells (37).

Differences were also found based on the size of green mussel shells. The abundance of microplastics was inversely proportional to the length of the shells, which can occur because the concentration of contaminants can inhibit shell growth (38). The concentration of microplastics is also affected by depuration rate (32). Small shells and pollutant materials easily enter their bodies, which can be called the absorption of pollutants along with their age. However, there will be times when mussels cannot tolerate the contaminants and stunt their growth, and less pollutants will accumulate. This is why many plastic contaminants were found in small sizes and a few were found in large sizes. Therefore, larger shells had a lower abundance of microplastics. Microplastic absorption can be affected by the filtration rate. There was a difference in the filtration rate between small and large green mussels. Small green mussels (2.8–3.0 cm) have a faster filtration rate than larger green mussels (6.8–7.0 cm) (39). This also shows that the ability of clams to absorb contaminants was greater in small shells. Previous studies have also found that the size of microplastics in the body of clams ranges from 0.25 4.5 mm (32). The size of microplastic particles in green mussels (*Perna viridis*) is influenced by the age of the shells and their size. Based on previous research, it was revealed that small shells can absorb contaminant substrates, including microplastics with a size of 0.15-3 mm and large sizes were often found to reach 5 mm (31).

Microplastic Determinants in Green Mussels

Mussels are filter feeder animals that obtain food by absorbing the water that passes into their body. The food that reaches the shellfish body is transferred with water and then extorted, followed by digestion with the help of the cilia (40). Clams eat small objects found on the bottom of the water, such as flagellates, protozoa, detritus, algae, zooplankton, phytoplankton, bacteria, and various substances that are suspended in their aquatic habitat. Apart from being a non-selective and sessile filter feeder animal, chemical contaminants are also quite high in their bodies because of this accumulation, and shellfish are also known as bioaccumulations. This clam of the genus Viridis is often called a highly specialized filter feeder and functions as a bioindicator of water pollution owing to its permanent nature, wide distribution, and ability to live in polluted areas (41). Microplastics can be detected in mussels even when they look healthy and edible during sorting, prior to sale or distribution. The signs of microplastics are not easily identifiable because of their small size.

Primary and secondary sources are the producers of microplastics in the environment. The primary source of microplastics is small particles, as well as the type of pellets used in the cosmetic industry and used as a base material for the plastic industry, such as microbeads in skin care products. The degradation of macro-sized plastics in the environment due to physical and chemical processes is a source of secondary microplastics (35). Larger plastic fragments carried by rivers, water runoff, sea tides, and wind are sources of microplastics. In addition, large concentrations of microplastics are produced by marine transportation activities (42). The absence of stringent policies and sanctions regarding the disposal of waste in rivers discourages people from paying attention to their impacts and dangers. Microplastics can absorb toxins from chemicals present in seawater and the surrounding environment. These properties result in chemicals that can be indirectly transferred to the food chain (43). Green mussels also have relatively low detoxification abilities; therefore, they cannot maximally remove toxic substances from their bodies (38). Mussels are also known as bioaccumulations because, apart from being non-selective and sessile filter feeder animals, chemical contaminants are also quite high in their bodies due to this accumulation.

Food product packaging made from plastic can potentially result in microplastic migration or the movement of monomer substances from plastic product packaging into the food chain, especially if the food does not match the packaging or storage container. Not all monomer substances or plastic additives must be monitored. Only a few compounds such as vinyl chloride, acrylonitrile, methacrylonitrile, vinylidene chloride, and styrene have been reported. Vinyl chloride and acrylonitrile monomers have high potential to cause cancer in humans. Vinyl chloride can react with guanine and cytosine in DNA. While acrylonitrile reacts with adenine (44). Vinyl acetate causes thyroid, uterine, and liver cancers in animals. Acrylonitrile causes birth defects in rats that eat it. Other monomers, such as acrylate, styrene, and methacrylate, and their derivative compounds, such as vinyl acetate, polyvinyl chloride, caprolactam, formaldehyde, cresol, organic isocyanate, hexa methylenediamine, melamine, epodilokchloridine, bisphenol, and acrylonitrile, can cause irritation to the digestive tract, especially the mouth, throat, and stomach. Plastic additives, types of plasticizers, stabilizers, and antioxidants can be sources of organoleptic pollution, which alters the taste and aroma of food and can cause poisoning (45). Styroform is another dangerous material that is considered safe by the public. Styrofoam containers are composed of polymers that are derived from chemical additives. The additives from these containers can migrate to packaged food, which is harmful to humans because they are carcinogenic. Styrofoam or plastic foam is commonly used as a protector for fragile materials and is also called fragile. However, Styrofoam is now one of the choices for food and beverage packaging materials. It should be noted that Styrofoam is still included in the plastic family with a building material called polystyrene, a type of plastic that is very light, translucent, stiff, and cheap but brittle quickly. The nature of the building materials, coupled with several other chemicals, will eventually produce Styrofoam, as is currently found. Styrofoam also contains chemicals, such as styrene, butyl hydroxy toluene, polytyrene, and CFCs. Styrofoam styrene can cause respiratory problems, skin irritation, and eye irritation at low levels and can cause cancer at high levels of use. Styrene and other additives contained in Styrofoam can be transferred from Styrofoam to food. When the chemicals in the styrofoam enter the food chain, they react with the food stored in it to become toxic and will cause health problems, especially in the endocrine and reproductive systems. The hotter the food or drink stored in the styrofoam container, the faster the toxic substances will transfer to the food. Therefore, the use of Styrofoam as a container for food or drinks is limited because of its carcinogenic properties. Butyl hydroxy toluene is an example of a plasticizer that imparts properties to plastics. It can only dissolve in fat and its derivatives (46). The intended type of microplastic is a conjecture or probability that may lead to the accumulation of microplastics in water. This research has not described the types of microplastics, as it only examines the determinants and management without discussing the types of microplastics that are generated.

Countermeasures Microplastics in Green Mussels

The use of plastic in modern life is growing rapidly because it is a practical, easy-to-obtain, and durable container that is available at low prices. Unfortunately, many people are ignorant of the dangers of plastics and are not capable of using them properly. Plastic is a material commonly found in almost every product. Starting with drinking bottles, food utensils (spoon, fork, container, glass), plastic bags, TV, refrigerators, plastic pipes, laminating plastics, dentures, toothbrushes, compact disks (CD), nail polish (nail polish), children's toys, machines, and military equipment. In addition, plastics are generally difficult to degrade (decompose) by microorganisms. Plastic waste can last for years and cause environmental pollution. The plastic decomposition process is estimated to take 100–500 years. Thus, the standard for the use of plastics must comply with applicable regulations to avoid its impact on health and the environment.

There is a restricted law regulating the handling of plastic waste in the sea. Restricted law is a quasi-legal instrument that has no legal force currently related to international law; it can be in the form of resolutions, declarations, guidelines, protocols, codes of ethics, communications, checklists, and rule (47). The World Charter is one of the restrictive laws that regulates the prevention of plastic waste in the sea for Nature 1982 (1982 Charter), which encourages the protection of the marine environment from plastic waste, as stated in number 11, stating that all activities that are expected to impact nature must be controlled, and maximize the best technology to minimize significant risks to nature, particularly in activities that are likely to cause irreversible damage to nature. In relation to binding regulations, not all countries are able to carry out and provide firmness in their implementation, such as the export and import of garbage and waste, which carries the risk of producing large microplastic particles (48). Countermeasures against microplastic pollution in the sea and green mussel biota include filtering waste disposal, policies on the use of waste plastic, and echoing the organic plastic brand (49). Plastic is a synthetic or semi-synthetic material that can be molded into any object while retaining its plastic characteristics. Plastics have the qualities of light weight, corrosion resistance, ease of fabrication, and low thermal and electrical conductivities. Plastics influence the implementation of industrial and structural projects. In addition, most plastics come in a variety of colors, which makes them a prime resource for decorative functions. In several countries, there are currently hundreds of plastic-producing factories that produce plastic products that are commonly used by the public. Plastics are also used to manufacture grocery bags and food packaging. Many bottles are made of plastic. Recycling is a prominent solution to combat plastic waste, processing plastic waste in addition to minimizing its accumulation in nature, and also produces products that have economic value. One way to address plastic waste is through fabrication (50). Additionally, biodegradable plastics have the potential to provide a more environmentally friendly solution compared to traditional plastic bags. As such, developing and utilizing biodegradable plastic materials in industry can have far-reaching economic advantages. This is a major advantage because biopolymers can reduce carbon dioxide emissions during the manufacturing process, and organic matter can be reduced after wasting (50).

CONCLUSION

Microplastic particles in green mussels (*Perna viridis*) found in water have several forms, including fibers, filaments, fragments, and granules, which are dominated by fibers. Each microplastic particle consisted of brown, purple, green, and blue colors. Microplastics range in size from < 1 to 5 mm. The highest abundance of microplastics was accumulated in green mussel gills compared to digestion. The determinant factors that result in the presence of microplastic particles in green mussel biota are human activities, shipping, and industrial waste. Countermeasures that can be taken to suppress the spread of microplastics are by include waste disposal filtration, policies on the use of waste plastic, and echoing organic plastic brands.

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