Scientific Research Publishing

Open Journal of Ecology, 2023, 13, 931-955
https://www.scirp.org/journal/oje
ISSN Online: 2162-1993
ISSN Print: 2162-1985

# Microplastics in Marine Environment: Occurrence, Distribution, and Extraction Methods in Marine Organisms

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**How to cite this paper:** Olubusoye, B.S., Oni, P., Owusu, F., Adekoya, O., Ongwech, A., Odogwu, D.A., Awolesi, O., Oje, A. and Arwenyo, B. (2023) Microplastics in Marine Environment: Occurrence, Distribution, and Extraction Methods in Marine Organisms. *Open Journal of Ecology*, **13**, 931-955.
https://doi.org/10.4236/oje.2023.1312057

**Received:** November 25, 2023
**Accepted:** December 26, 2023
**Published:** December 29, 2023



## Abstract

The pervasive presence of microplastics in marine environments has raised significant concerns. This review addresses the pressing issue of microplastic pollution in marine ecosystems and its potential implications for both the environment and human health. It outlines the current state of microplastic occurrence, distribution, and extraction methods within marine organisms. Microplastics have emerged as a significant environmental concern due to their harmful effects on ecosystems and their potential human health risks. These particles infiltrate marine environments through runoff and atmospheric deposition, ultimately contaminating beaches and posing threats to marine life. Despite the gravity of this issue, there has been limited research on the presence and distribution of microplastics in marine organisms. This review aims to bridge this knowledge gap by comprehensively examining the occurrence, distribution, and various extraction methods used to detect microplastics in marine organisms. It emphasizes the urgent need for targeted measures to manage microplastic pollution, highlights the significant role of human activities in contributing to this problem, and underscores the importance of reducing human-induced pollution to safeguard marine ecosystems. While this paper contributes to the understanding of microplastic pollution in marine environments and underscores the critical importance of taking action to protect marine organisms and preserve our oceans for future

generations, it also emphasizes that, in effectively tackling the microplastic problem, a well-coordinated approach is essential, involving research initiatives, policy adjustments, public involvement, and innovative technologies. Crucially, prompt and resolute responses must exist to counteract the escalating peril posed by microplastics to the oceans and the global environment.

## Keywords

Microplastics, Marine Environment, Marine Organisms, Extraction Methods, Ecological Impact, Ocean Pollution

## 1. Introduction

The prevalence of plastics in our daily lives is an important environmental issue that is being addressed in the twenty-first century [1]. Each year, a staggering 300 million tons of plastic waste are discarded into our oceans, comprising items like plastic bags, discarded fishing gear, food containers, and bottles. Like other emerging contaminants (such as heavy metals and PFAS), these pollutants infiltrate marine environments through various avenues, including rivers, coastal sewers, floods, and wind, ultimately contaminating our once-pristine beaches and resorts [2] [3] [4]. The combined impact of multiple contaminants underscores the complex challenges associated with maintaining the health and integrity of marine environments. This surge in plastic and microplastic presence stands as one of the gravest threats to marine life and the environment, resulting from human activities both on land and at sea [5].

Microplastics, defined as plastic particles measuring less than 5 mm in size, come in two distinct categories: primary microplastics and secondary microplastics [6]. Primary microplastics include products used in households and industries, such as cosmetics, cleansers, insect repellents, and sunscreens [7]. They also result from the ship-breaking industry and air-blasting technology. Secondary microplastics are smaller fragments that develop over time from the degradation of larger plastic items in terrestrial and marine environments [7].

Microplastics are not individual entities but rather a mixture of polymers and additives that can absorb substances from the surrounding environment, including pollutants and nutrients [5]. Recently, airborne tire wear particles (TWPs)–a class of microplastics pollution-were reported to contain toxic compounds such as 6PPD-Q and 4-ADPA that can leach from these TWPs via urban stormwater runoff posing health risks to marine organisms [8]. The presence of microplastics in aquatic environments is a global concern due to their toxicity and persistence. They can serve as vectors for various pollutants and emerging contaminants in marine organisms [9]. Chemical additives used in plastic manufacturing, environmental contaminants absorbed on plastic surfaces, and heavy metals can have harmful effects on marine biota, including disruption of metabolic and reproductive activity, weakened immune response, oxidative stress,

cellular toxicity, inflammation, and even cancer [5] [10] [11] [12] [13] [14].

Moreover, microplastics increase chemical substances' bioavailability and bioaccumulation risk in marine organisms, as these particles can be ingested [15] [16]. In recent years, microplastics have been recognized as emerging pollutants and a significant threat to marine organisms and ecosystems worldwide [5]. If their accumulation continues at the current rate, it is predicted that by 2050, there will be more microplastics than fish in the oceans.

This is a critical environmental issue because the pervasive presence of microplastics has far-reaching consequences for marine ecosystems and, by extension, human well-being [17] [18]. The effects of microplastics are not confined to the immediate marine environment; they have the potential to disrupt entire food chains and ecosystems [19].

One concerning aspect is the bioaccumulation of microplastics. As marine organisms ingest these tiny plastic particles, they can become carriers of pollutants that adhere to the surfaces of microplastics [20]. When larger organisms consume the contaminated prey, the pollutants can biomagnify through the food web, resulting in potentially harmful concentrations in apex predators, including species consumed by humans [21] [22]. This raises significant concerns about the safety of seafood and the potential transfer of contaminants up the food chain to human consumers.

The impact of microplastics extends beyond direct ingestion and bioaccumulation. Their presence in aquatic ecosystems can disrupt nutrient cycling and alter microbial communities, potentially affecting the health of the entire ecosystem [23]. Moreover, the ingestion of microplastics by filter-feeding organisms, such as mussels and oysters, can lead to reduced feeding efficiency, impaired growth, and compromised reproduction [24] [25]. These effects reverberate throughout the ecosystem, potentially causing cascading impacts on other species [26] [27].

Although many studies have examined the sources, fate, transport, and toxicity of microplastics in terrestrial and marine environments [1] [4] [28] [29] [30] [31], a few have focused on the occurrence, distribution, and extraction methods of microplastics in marine organisms. To bridge this knowledge gap, this review provides a comprehensive overview of the occurrence, distribution, and extraction methods of microplastics in marine organisms to present current data on the presence and distribution of microplastics in marine environments worldwide in a bid to understand the extent of microplastics pollution and their potential effects in marine ecosystems, while discussing the pros and cons of different extraction methods of MPs in marine organisms.

## 2. Occurrence, Abundance, and Distribution of Microplastics in Marine Habitat

Plastic was introduced for the sole purpose of creating convenience for people. However, it has become a burden due to its persistent nature. Plastic pollution of

the marine environment, particularly oceans and inland waters has become a global issue because of the threats it poses to humans and aquatic bodies. It is estimated that if this is left unabated, it could be 12 billion tons affecting most of the globe by 2050 [32]. Microplastics are quite harmful to living organisms [33] [34] and have become a growing cause of concern because they affect marine habitats and the lifeforms of organisms.

It is even more dangerous with the reality that these microplastics can easily enter into marine habitats alongside wastewater, drainage systems, litter from the environment, washing clothes, and fertilizer [35]. Microplastics are broadly classified into two. These are primary and secondary sources. In **Figure 1** below, these sources are exemplified, including their pathway into the aquatic ecosystem.

The primary source of microplastic is mainly specific industrial sectors. They are mostly used for specific industrial applications. Mechanical exfoliants like cosmetics, healthcare products, sunscreen, and toothpaste are some of the common examples of primary sources of MPs [6] (Many of these items are commonly used as such it is not surprising to see that its users discard them inappropriately [36].

The secondary source of microplastics forms in the marine environment due to the fragmentation of larger plastics into fine matter. These items are commonly released into the marine environment through bottles, pipes, clothing, nets, and plastic sheets. Microplastics make up 95% of the pollutants that are found in marine habitats. Interestingly, these pollutants accumulate and spread over the marine environment, water surfaces, and sea floors [37].

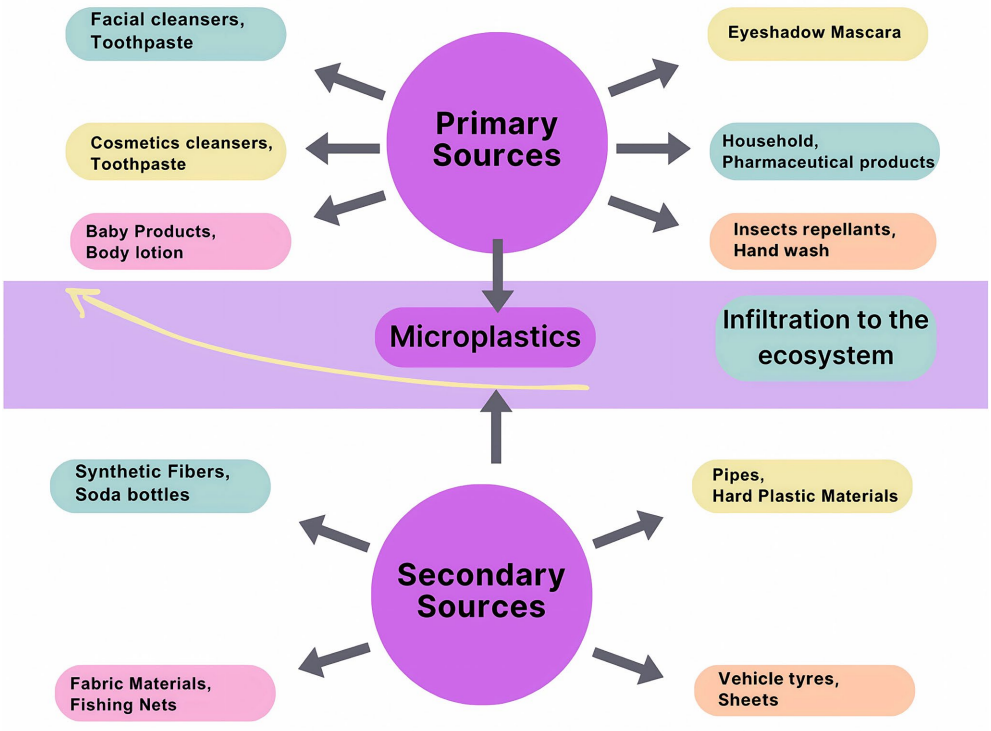


**Figure 1.** Exemplary sources of microplastics that infiltrate the marine environment.

MPs get into the marine habitat through the movement of wind, sewer, and even tidal processes and these affect the aquatic organisms that consume these microplastics [38] [39]. In the bodies of these aquatic bodies, the plastics can be broken down into smaller parts due to stress, biological processes, and even changes in temperature. These contaminants have pores that easily absorb chemicals from their surroundings and can transport these components to living things. Unfortunately, when these marine organisms consume these toxic components, it reduces immune function, affects growth, and even results in oxidative stress for the organisms. MPs can easily enter freshwater and marine environments if not properly managed and this will have dire consequences. Sadly, many aquatic organisms mistake these microplastics for foods and as such, they consume them [40]. When aquatic organisms consume these toxic substances as food, it can cause chemical and physical properties. These plastics when consumed by aquatic organisms can cause blockage in the digestive system and cause reduced growth of the animals [41]. This is not all as different chemicals and metals can stay associated with these microplastics and affect the lives of aquatic animals [42].

Microplastics infiltration has become very prevalent, with algae being mostly affected by this infiltration [43]. Unfortunately, it doesn't end with algae as its consumption can also pose a risk to humans. There have been instances of MPs going into the food chain and affecting people who consume such foods. Special attention is drawn to MPs because they have been detected in human-related foods like table salt, milk, beer, and honey [44]. Microplastics pollution has left a negative impact on the economy and even public health. These microplastics are known to pose serious health concerns to humans because of their toxic effects. Unsuspecting individuals get affected by these microplastics by inhaling the substance in the air or through dermal infusion.

Although there are different methods of identifying microplastics, they are broadly classified into two types such as physical and instrument-based methods. However, the instrument-based method is considered to be more reliable for identifying microplastics. Considering plastics account for about 80% of marine litter, it becomes necessary to control the pollution caused by these microplastics [45]. One of the ways to control this pollution is through the introduction of strict regulations to control all aspects of marine resources. An example of such regulations is the United Nations Convention on the Law of the Sea (UNCLOS). UNCLOS emphasizes the need for nations to establish a framework to control the pollution caused by waste dumping. Another marine pollution control is recycling plastic materials. When the recycling rate of plastics is increased it can reduce pollution caused by plastics use and production. Plastic waste should be properly treated to prevent environmental pollution in the future.

## 3. Occurrence, Abundance, and Distribution of Microplastics in Marine Organisms

One of the main sources of microplastic contamination in marine organisms is

secondary microplastics, which are produced as a result of the degradability and fragmentation of primary microplastics [46] [47]. The most prevalent form of polymer discovered, Polyethylene, makes up 23% of total consumption. It is followed by polystyrene (22%), polypropylene (12%), polyester (9%), and polyamide (6%). In selected studies, fibers and fragments were the most often ingested substances in terms of shape, with consumption rates of 23% and 21%, respectively [48].

An important biological system that depicts the movement of energy and nutrients through the ocean ecosystem is the food chain of marine organisms. Primary producers like phytoplankton and algae are where it all starts because they use light and nutrients to generate organic matter via a process called photosynthesis [49]. These producers are consumed by primary consumers like zooplankton and herbivorous fish. Primary consumers are consumed by secondary consumers like predatory fish and cephalopods [50]. The highest trophic levels are populated by tertiary consumers like apex predators and marine mammals. Detritivores and decomposers, including bacteria and crabs, disintegrate organic materials and dead organisms to recycle nutrients back into the ecosystem [51]. Different organisms with adaptable diets and roles in different trophic levels make up the interconnected and complex marine food chains. Given the importance of each level in the marine food chain, microplastics contamination at any level would have a significant effect [52].

All marine organisms at various levels of the food chain have the potential to consume MPs and related contaminants through a number of different routes, such as inhalation at the air-water interface, filter/suspension feeding, consumption of prey that has been exposed to MPs, and direct ingestion [53] [54]. They can also bioaccumulate a wide variety of MPs with various sizes, colors, shapes, and polymeric compositions [55]. Yet, it is generally recognized that ingestion is the primary method through which MPs accumulate in aquatic organisms [56]. Additionally, small-sized MPs are ingested by organisms of various feeding types, allowing biological interaction, because they overlap or come into contact with the size range of their prey [57] [58].

According to Cáceres-Farias *et al.* [59], fish was observed to have the highest microplastics abundance (75% ± 12.0%), followed by mollusks (90% ± 3.5%) and crustaceans (20% ± 7.0%). Filter feeders like mussels and oysters might possibly ingest microplastics. The prevalence of microplastic contamination in the soft bodies of several mussel species has previously been estimated to reach 97% [60]. Another study found that the mussel species *Mytella charruana* was observed to have a prevalence of 87% of microplastic particles in its soft body. In other recent investigations, mollusks with prevalence of 83% and 47%, respectively, including the Pacific oyster *Crassostrea gigas* and the palmate oyster *Saccostrea palmula* [61]. Another research found that *Crassostrea cf. corteziensis*, one of the species with the greatest plastic pollution, had a prevalence of microplastic particles of 93% [59]. On an ecological level, however, the consumption of microplastics by bivalves has shown a number of adverse effects on molluscs, including oxidative damage, immunological response, and cytotoxicity [62].

Microplastics have been found in crustaceans, where they are present in 53% of crustaceans in the North Pacific zone and 20% of penaeid shrimps in the Tropical Pacific [63]. Plastics can get caught as crabs push water over their gills to take in oxygen. For instance, crustaceans exposed to polystyrene microbeads exhibit reduced fecundity, delayed growth of offspring, reduced intake of food, impaired enzyme function, and altered behavior [64].

Fishes, when exposed to MPs, may ingest through their gills and digestive systems [64]. In another research, the glassfish, *Ambassis dussumieri*, had a reduced body length when exposed to microplastics than when treated as a control, and the probability of surviving was similarly lower than those of the controls [65]. Difficulty in feeding due to the blockages in digestive organs was caused by larger microparticles [66]. This blockage and irritation in the gastrointestinal tract led to reduced feeding which would lead to decreased nutrient intake [67]. Furthermore, it was shown that MPs in fish species' gills, livers, and digestive tracts promote inflammation, oxidative stress, and disturbed energy metabolism [68].

## 4. Microplastics Extraction in Marine Organisms

Microplastics serve as a conduit for conveying absorbed persistent organic pollutants, heavy metals, fish pathogenic bacteria, and multi-drug resistant *E. coli* [69] [70] which may have harmful impacts on marine organisms, and hence the need for microplastic extraction. Microplastics have been identified in a range of marine organisms spanning varying ecological pyramids including including cetaceans, bivalves, zooplankton, worms, and seabirds [71] [72].

Identifying, measuring, and extracting microplastics from marine organisms using scientific methods can be challenging [73] and require specialized techniques and equipment. Several works of literature on microplastic extraction from the environment apply multiple extraction techniques including density separation, sieving, digestion, and filtration [74] [75] for MP extraction from sediments, marine organisms, and water samples but the one technique specific to extraction from marine organisms have been chemical digestion for most studies [75] [76] [77]. The path to MP detection in food items is illustrated in **Figure 2**, and the subsections that follow elucidate important extraction methods. Identification and extraction of MPs from organisms provide an understanding of the extent of marine pollution and prevent further harm to living marine organisms.

### 4.1. The Digestion Process

The digestion process allows researchers to isolate and study microplastics from marine organisms in a controlled laboratory environment using different forms of chemicals including acid [79], alkaline [80], oxidizing agents [81], and enzymes. In laboratory settings, a chemical digestion approach can be applied to extract microplastics from the gastrointestinal tracts of marine organisms [82] [83]. This technique is commonly used for MP extraction in fat fish species [83],

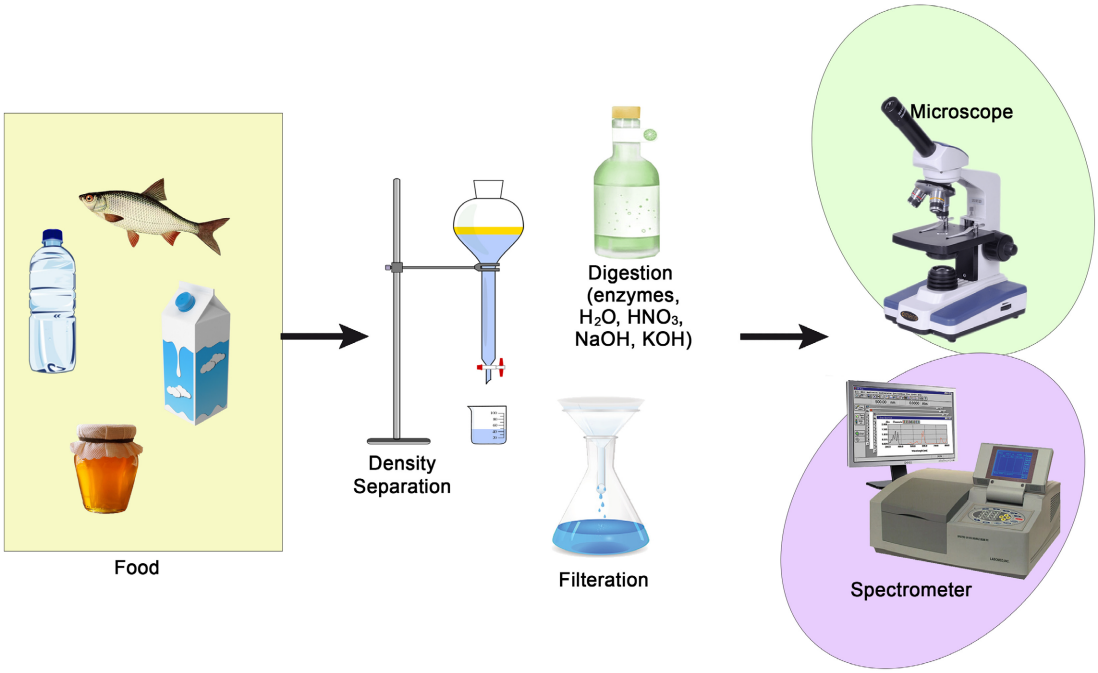


**Figure 2.** Microplastic detection stage [78].

zooplankton, phytoplanktons, bivalves, crustaceans, and polychaete [15] [75] and other marine species. Extraction is conducted on dead species similar to a necropsy (an animal autopsy) where the plastic debris is carefully separated and removed using chemical solutions at different densities, oxidizers, acids, or alkaline substances. The forms of digestion applied in the extraction of MP in marine organisms are described in the subsections that follow.

#### 4.1.1. Acid Digestion

The most commonly used acids for digestion during the extraction of microplastics include the strong acids nitric ($HNO_3$), Perchloric ($HClO_4$), formic ($CH_2O_2$), hydrochloric (HCl) [76] and rarely peroxymonosulphuric ($H_2SO_5$) [79]. The weaker acids ascorbic ($C_6H_8O_6$) and citric ($C_6H_8O_7$) are mainly used as enhancers and or buffers [76]. The major advantage associated with the application of strong acid digestion lies in their effective (94% - 98%) biogenic matter destruction [84]. However, research has shown that the conditions under which the acids must be applied for effective biogenic destruction pose major drawbacks because they have deleterious effects on some of the plastics to be extracted. Such conditions include; 95% $HNO_3$ [85], 69% $HNO_3$ [86] heat treatment 60˚C, 80˚C, 2 h [79], 80˚C, 3 h [87], 100˚C, 2 h [85]; prolonged extraction time such as overnight [88], 96 hours [86] and using the acids in combination; $HNO_3$:$HClO_4$ (4:1 v:v), HCl:$HNO_3$, (1:3 v:v) [74].

Generally, at high concentrations and temperatures, the strong acids namely nitric, hydrofluoric, Perchloric, peroxymonosulphuric, and sulphuric severely degrade MPs. peroxymonosulphuric, and sulphuric are likely severely damaged [86]. Li *et al.* [89] reported the complete removal of the tissues of the banana

prawn GIT but also the significant degradation of seven reference polymers (polyamide (PA), polyethylene (PE), polyester (PES), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and rayon) by concentrated acid digestion treatment. Avio *et al.* [77] reported a recovery of only 4% for PE and 4 ± 3% for PS respectively from 22.5 M nitric acid after 12 h at room temperature followed by 30 min boiling. In a related study, Schrank *et al.* [79] reported increased stability of PE and PS with recoveries of 95% - 100% and 49% respectively upon boiling with 15.7M nitric acid for 2 h suggesting improvement of MPs stability by lowering concentrations of digestants. Schrank *et al.* [79] also reported the complete dissolution and destruction of PA, PET, and PUR by hot nitric acid (80˚C, 15.7 M $HNO_3$, 2 h).

Peroxymonosulphuric ($H_2SO_5$) (Caro's) acid, a very highly activated and strongly oxidizing acid made by mixing $H_2O_2$ with concentrated $H_2SO_4$ has been reported to severely degrade polyurethane (PUR) and PA during extraction of MPs [79]. Formic ($CH_2O_2$) has also been suggested as a digestive agent and was used (3%, 72 h) to decalcify polyps to assist in the visualization of ingested blue polypropylene shavings [89]. HCl, though known for its low digestion efficiency, has been reported to cause disintegration of PA, clumping of PET, and surface modifications to PVC by exposure at (37%, 25˚C 6 h) [86]. In combination with concentrated nitric acid (HCl: $HNO_3$, 1:3), the aqua regia is a potent oxidizing agent though still less aggressive than pure concentrated nitric acid. PA can however be degraded even by a 5% HCl [90]. Furthermore, (PA, Nylon), polyester, (PET) and polycarbonate have minimal resistance to acids, even at very mild concentrations [91].

Given all the above, Rani *et al.* [74] and Joano *et al.* [92], suggested the imposition of limits to the use of acidic digestion or utilizing it with extreme caution and presumably when other approaches fail. Dellisanti *et al.* [93], reported the frequency of use for the various methods of digestion of mussels to be in the order; alkaline (46%) > oxidative (28%) > mixed chemical (12%) > enzymatic (8%) and acidic digestions (6%). 32% of these treatments were paired up with density separation steps using NaCl solution for efficacy. A similar trend was observed for fish; alkaline (56%) > oxidative (12%,) > mixed chemicals (10%) > acids (8%) >enzymes (4%) [93].

Despite the drawbacks mentioned above however, acid digestion has been applied in the extraction of MPs from several marine organisms including fish [94], shellfish [95], crabs [96] [97], mussels [85], banana prawn gut [89], digestive tract of decapods [84] [97], copepods and euphausiids [87] and bivalves, polyps [89] among others.

#### 4.1.2. Alkaline Digestion

Alkaline digestion applies basic solutions such as potassium hydroxide (KOH) [98], sodium hydroxide (NaOH), and sometimes the weak base sodium hypochlorite (NaClO) [74]. These are used to digest animal tissues through hydrolysis and denaturation of proteins [99]. KOH (10%, 1.26M) has been the most

frequently used during the extraction of MPs because of its relatively mild damage to MPs compared to other chemicals such as NaOH [84]. It was applied to successfully digest the GIT of fish during a 2 - 3 week incubation [100]. KOH: NaClO (1:1, v/v) combination was reported to give the highest efficiency in the fish stomach by destroying adhering biofilms composed of polysaccharides, proteins, and lipids [84]. NaOH has been used to successfully digest muscle tissue [88] and the GIT of fish with an additional neutralization step using HNO3. However, it does not give a satisfactory digestion of the other tissues of fish [86]. Protocols employing the use of KOH (10%, 10:1 v: w) for tissue digestion, normally involve oven incubation at 40˚C for a treatment period of 72 to 120 hours or even more [86] [89]; baking (450˚C, 6 h)or incubation (60˚C overnight) [101] [102]. The recoveries of plastics (≥95%) are generally good but such strongly alkaline conditions are destructive to some plastics such as PET with reported recovery (70% - 75%) for 10 M NaOH digestions. The recovery increases at lower concentrations such as 1M [80]. However, even such a low concentration (1M) was reported to destroy LDPE when digested for 2 days at room temperature signifying the negative impact of a prolonged digestion period [103]. The temperature raised to 60˚C increased the digestion efficiency in fish to 91% and 98% using NaOH and KOH respectively. However, elevated temperature was associated with surface damage and reduced recovery rate of some plastics such as PET, PC PE, and PVC Dellisanti *et al.*, [93]; Karami *et al.* [86] further report that KOH (10%, 50˚C - 60˚C) changes the color of Nylon 66. KOH is also reported to be ineffective when applied in the digestion of decapod intestinal tracts [104]. Another drawback to KOH digestion is the massive saponification that normally accompanies its use with fish and other lipid-rich tissues. The resultant soapy material normally encases MPs, lowering their recoveries, and clogs filters which may demand an additional step requiring the use of methanol or ethanol [105].

Despite some of the drawbacks cited, however, the use of KOH remains the most cost-effective, utilizing cheaper and common chemicals and demanding simple sampling procedures [101] [102] [103]. It has been applied in the digestion of several tissues including plankton [106] [107], oysters [108], shellfish and bivalves [102], prawns and mussels [104], crabs [98] and mussels [101].

#### 4.1.3. Enzymatic Digestion

This involves the use of enzymes such as protease-K [109], trypsin, Corolase 7089 [88], Alcalase [110], pancreatic enzymes [111], lipase, chitinase, cellulase [112], papain and collagenase [113]. It is a biologically specific means of hydrolyzing proteins and breaking down tissues [114]. The process has been applied to remove complex organic matrices by modifying multi-step protocols according to the matrix composition [115]. Enzymatic digestion is either used alone or sometimes in combination with other digestion methods to eliminate major proteins, lipids, and carbohydrates [115]. The advantages of enzymatic digestion over the other procedures stem from the fact that it registers no loss, degradation, or surface alteration of MPs and is also less hazardous to human health

[116]. The enzyme Pepsin causes no damage to polymers but proved only partially effective at digesting biogenic material [117]. In some instances, low-cost enzymes (lipase, amylase, chitinase, and cellulase) have been effectively utilized in the removal of plastic particles from muscle tissue samples [118]. Further, by manipulation of digestion factors of temperature (50˚C), the concentration of Proteinase-K, and prolonging the incubation period, the low efficacy (88%) was raised to 97% [109].

Enzymes do not interact with polymers, and conserve plastics while removing organic materials. For example, chitin exoskeletons have been eliminated by a method for complex samples utilizing chitinase enzymes [115]. On the other hand, Uurasjärvi *et al.* [119] used a four-step and 8-day procedure to dissolve marine samples containing chitinaceous materials. They involved the use of a combination of $H_2O_2$, the enzyme chitinase, and sodium dodecyl sulfate (SDS). The use of optimized protocols combining proteinase-K and sodium perchlorate ($NaClO_4$), obtained high digestion efficiency (>97%) and did not cause any destructive effect on PS, PE, PVC, nylon, and polyester [109].

Whereas enzymes can break down biomass and facilitate the extraction process of MPs with little damage [116], their use has several drawbacks. First, the Proteinase-K that gives very good results is very expensive [120]. Secondly, the specificity of enzymes implies a large volume of mixed enzymes may be required to target different proteins to achieve complete digestion of the target biomass, and this may lower the economic viability of the process [121]. Thirdly, the use of a Universal Enzymatic Digestion Protocol (UEPP) [115] targeting a wide range of biological matrices needs a preliminary evaluation of the matrix composition to select the proper digestion steps [115]. The more steps the greater the chances of contamination, and loss of MPs, and the heavier the workload to the personnel [114]. Another drawback is that this method may not be applicable when targeting fragments of biodegradable polymers that are deliberately designed to be degraded by enzymes [88]. Furthermore, several enzymatic protocols have been evaluated mainly on smaller-sized organisms (e.g., 0.15 - 0.33 g) [122] possibly due to the cost and time involved. Finally, the digestion efficiencies of enzyme protocols are also relatively lower compared to other extraction methods [112].

Nevertheless, enzymes can be used singly, in combination, or along with other chemical digestion methods by targeting specific biomass that is not readily digestible by the available chemicals. For example, it has been applied in plankton samples and copepods [109], mussels [88], bivalve tissues [111], intestinal tracts of turtles [88], and zooplankton [90].

### 4.2. Density Separation

Density separation involves the use of high-density (1.2 - 1.5 $g{\cdot}mL^{-1}$) medium, usually a solution of sodium chloride (NaCl), sodium iodide (NaI), sodium tungstate ($NaWO_4$), calcium chloride ($CaCl_2$) or zinc chloride ($ZnCl_2$) in isolating partially inorganic biomass such as bone fragments, chitin, and grits [81]

[123]. The lower-density microplastics normally float to the surface and are collected. Density separation can be useful in studies following digestion [90] or for reducing the sample size before removing organic material by purification [79]. The most commonly used solution is that of sodium chloride (NaCl) because it is cheaper, non-hazardous, able to increase the initial density of a solution when added in the correct quantity, and yields a sufficiently good recovery ≥ 63% [124]. However, NaCl produces a density of only 1.2 g/mL, hence may not apply to higher-density plastics, such as PET, PVC, and PUR, as well as HDPE, PS, PA, and ABS (2.2 g/mL) [74] [114]. NaI (aq) and $ZnCl_2$ (aq) could therefore form viable alternatives to NaCl (aq) because their higher densities (>1.6 g/mL), make them capable of floating the high-density plastics. However, they are both toxic to the environment and humans and expensive [125]. $ZnCl_2$, NaI, and $CaCl_2$ solutions (density 1.6 - 1.8 g/mL), alternatives to NaCl for higher-density plastics are corrosive and acidic and are likely to be aggressive towards some plastics [126]. Furthermore, NaI is hygroscopic, and its storage, recycling, and reuse may be very difficult. In some instances, the low density of NaCl has been raised (1.3 g/mL) by adding sucrose ($C_{12}H_{22}O_{11}$), or table sugar to cater for higher density MPs [127]. With respect to marine organisms such as fish, the process of density separation which occurs after digestion is illustrated in **Figure 3**. It begins with the removal of GIT or gill, followed by the alkaline digestion of the sample for 72 hours above room temperature. This can be followed by vacuum filtration, microscopic analysis, and the use of spectroscopic methods to ascertain MP types and their associated components or compounds.

Another issue with the density separation step is the risk of sample loss or contamination caused by repeated sample transfer, re-suspension, and retrieval of MPs [93]. Drawback also comes from the fact that during the density separation process, organic matter may float together with plastic particles, making it difficult to distinguish the two, necessitating the need for further treatments such as chemical digestion [128].

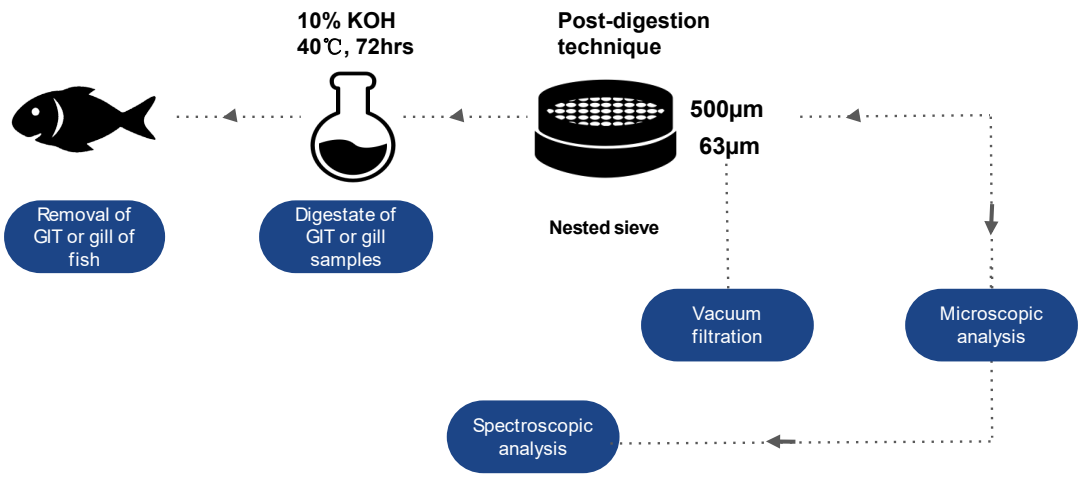


**Figure 3.** Post-digestion method of extracting MP from Gastrointestinal Tract and gills of fish.

## 5. Practical Implications and Future Direction

In general, microplastics are more abundant near densely populated areas, on beaches and on infralittoral sediments [129]. The world's freshwaters, soils, oceans, and air are progressively contaminated with tiny plastic particles, fragments, and fibers. Microplastics, which are now ubiquitous in the natural environment, originate from different sources along plastic product's lifecycle [129] [130]. They are extremely persistent in the marine environment and thus, accumulate at increasing and or overwhelming rates [131]. Due to their small sizes, varied colors and different shapes, several marine species routinely mistake and ingest microplastics as food [131] [132]. Microplastics are commonly ingested by aquatic species including plankton and large marine mammals [132]. Humans are also exposed to microplastics through the ingestion of microplastics contaminated seafood, beverages or by inhaling airborne microplastics [132].

While some studies have been done on microplastics extractions and quantification in marine organisms and water environments, most studies were done at laboratory levels. Furthermore, laboratory experiments have shown that plastic-sorbed chemicals can transfer into organisms upon ingestion [133]. However, studies distinguishing the effects of additives on microplastics are scarce. Also, at the environmental levels, there is no clear information on whether the ingestion of plastic containing sorbed contaminants and additives by marine organisms can influence the bioaccumulation of these substances. Thus, there are growing concerns over the environmental and human health bearings linked to the continued exposure to microplastics. The possibility of long-term and irrevocable risks to human health and ecosystems demands mitigation actions to be taken to halt plastics and microplastics accumulations in the environment.

### 5.1. Plastics and Greenhouse Gas (GHG) Emissions

In addition to the potential threats to ecosystems, recent studies indicated that a significant amount of Greenhouse gasses (GHG) are being emitted as plastic waste breaks down into smaller pieces. Polyethylene is the highest emitter of both Methane and ethylene due to exposure to sunlight [134]. When exposed to solar radiations, unrecycled or improperly disposed plastics generate GHG both in water and air. The Global GHG emissions from plastics are expected to reach 1.34 gigatons per year by 2030 and 2.8 gigatons per year by 2050 [135]. It is reported that the global incineration of plastic waste and annual plastic production gives rise to about 400 million tons of $CO_2$ [136]. The plastic industry is reported to account for approximately 6% of the global oil consumption and is expected to reach 20 percent by 2050 [137].

### 5.2. Governance Approaches to Microplastics' Pollution

Plastic pollution in the marine environment is undoubtedly a global problem that requires an urgent intervention. While microplastic pollution has attained substantial attention from researchers and the public, efforts to tackle microplas-

tics pollution globally have been restricted because of weak and fragmented acts [131] [138]. Although microplastics are an internationally recognized pollutant, there are no formal management strategies currently [139]. Most developed actions have focused on larger plastics, specifically, plastic bags [138]. Moreover, the reuse and recycling of plastics is very low compared with other materials including paper, glass, and metals [136].

To limit plastic use and minimize marine environmental pollution, almost 150 countries have executed some form of legislation to eliminate single plastic use [132]. Despite all these efforts, there exists a significant gap in developing a clear policy and governance mitigation response. Addressing the microplastic problem is crucial for achieving and realizing sustainable ocean governance and the 2030 Sustainable Development Goals [140].

## 6. Conclusion

This paper has successfully reviewed the occurrence, distribution, and extraction methods of microplastics in marine organisms, and consequently, practical implications have been posited. Indeed, microplastics present a multifaceted challenge when it comes to waste management and remediation. Their diminutive size makes them exceptionally challenging to capture and remove from aquatic environments, rendering mitigation efforts quite demanding. To effectively tackle the microplastics issue, a comprehensive approach is necessary. This includes enhancing waste management practices, reducing plastic consumption at its source, and pioneering innovative technologies designed specifically for the removal of microplastics from water bodies. Moreover, fostering public awareness and education regarding microplastics and their environmental impact is of paramount importance. Engaging individuals and communities in initiatives aimed at curbing plastic consumption, advocating responsible waste disposal practices, and supporting policies geared toward combating plastic pollution are essential for implementing enduring solutions. The proliferation of microplastics in aquatic environments represents a multifaceted and pressing environmental challenge. Its repercussions extend well beyond immediate marine ecosystems, impacting the entire ecological food chain and potentially posing risks to human health. Effectively addressing this issue demands a well-coordinated effort involving research, policy reforms, public engagement, and the advancement of cutting-edge technologies. It is of utmost importance that we respond promptly and decisively to confront the escalating threat posed by microplastics to our oceans and the global environment as a whole.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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