

Microplastics in the Marine Environment: Current Status, Assessment Methodologies, Impacts and Solutions

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Abstract

Microplastics exhibit a global distribution and have been detected in all levels of the marine environment. The most visible and disturbing impact of microplastics are their ingestion and consequent suffocation of hundreds of marine species. Microplastics can contribute considerably to the transport of non-indigenous marine species to a new area thereby threatening the marine biodiversity and the food web. They can also accumulate toxic substances on their surface therefore represent a potential concentrated source of environmental pollution or act as a vector of toxic pollutants in the food web with some severe health implications. Therefore, assessment of the status, effect and mitigations are needed. The current status, effects and solutions to the occurrence of microplastics in the marine environments were conducted by reviewing most of the literatures on the subject matter. Here, we particularly discussed old and new techniques for extracting and quantifying microplastics from marine matrices. Although, it is an intricate and herculean task to address the problems of microplastics in the ocean, some of the approaches to mitigate them are discussed.

Keywords: Microplastics; Marine environment; Impact; Mitigate

Introduction and Historical Background

Plastic pollution has become a global environmental issue as plastic debris has reached and is found in all oceans of the world with adverse impacts on marine biota, biodiversity as well as human health [1]. Although, the threats posed by plastics to the marine environment were initially ignored for a long time, they recently gained attraction and recognition [2]. Since the development of the first plastic “Bakelite” in 1907, a number of cheap production techniques have been developed to mass produce the modern day plastics [3]. Plastics started to enter the ocean in increasing quantities from the 1950s from a wide variety of land and sea based sources; river, run-off, beach-goers and tourists, ship [4]. Although, there are no reliable estimates of the inputs at a regional or global scale, the trend assumed that the total quantities have increased over the years as in Figure 1 [5]. In 1975 alone, it was estimated that the world’s fishing fleet dumped into the ocean approximately 135,400 tons of plastic fishing gears and 23,600 tons of packaging materials [6,7]. A survey carried out in South African beaches in 5-year intervals revealed that the quantities of plastic debris dumped increased tremendously over the years. Plastics, which are synthetic polymers, are still one of the most widely used and versatile materials in the world [8]. The global production of plastic in 2012 was 288 million tonnes [9]. They are light-weight, highly durable, strong and cheap [10]. These properties make them suitable to produce a wide range of products, persistent and hazardous in the environment [10]. Their buoyancy makes them to be dispersed over a long distance and finally settle in the sediment where they persist for centuries [11]. One major aspect of plastic pollution is the occurrence of microplastics in the aquatic ecosystems. Through some physical, chemical and biological processes such as UV-light, wave action, ocean-current, suspension and resuspension of plastics, large plastic debris fragments can degrade into micro-sized plastic commonly referred to as Microplastics. Microplastics is defined as the plastic particles in the size range of 1 nm to <5 mm [5]. The scientific community is currently focusing on microplastics more than plastics because they tend to pose a greater threat to marine biota and increasing changes in the integrity of the habitats at alarming rate globally [12]. For instance, microplastic ingestion has been recorded in a wide variety of marine biota [13,14] resulting in physiological disorders [15]. Therefore,

since the issue of microplastics in the environment is a global intricate subject matter with environmental, economic and health implications and is a new rapidly evolving area of marine research that requires local and international attentions. This prompts and arouses interest and necessitates writing of this review article whose objectives are;

1. To review the various microplastics assessment methodologies for different marine matrices (Sampling and Analytical Methods).
2. To summarize the biological and ecological impacts of microplastics on marine biota and the environment.
3. To review the solutions to mitigate the disposal, occurrence and curb the menace of microplastics in the ocean.

Distribution of Microplastics in the Marine Environment

Microplastics have been found in most marine habitats of the world and throughout the water column. Understanding the distribution of microplastics both vertically and horizontally in the oceans, between geographic regions, between open and enclosed seas, between various compartments which can be surface, mid-water and benthic sediments, is a requirement for assessing the potential impacts on the marine biota and the environment [5]. Although, the major sources of microplastics are land based (urban and storm run-off, beach-visitors, industrial activities, construction and illegal dumping, inadequate waste disposal [16,17], in general, it is extremely difficult to identify and point out the ultimate sources of microplastics due to their fragmentation and

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Received March 08, 2016; **Accepted** March 29, 2016; **Published** April 04, 2016

Citation: Ogunola OS, Palanisami T (2016) Microplastics in the Marine Environment: Current Status, Assessment Methodologies, Impacts and Solutions. J Pollut Eff Cont 4: 161. doi:10.4172/2375-4397.1000161

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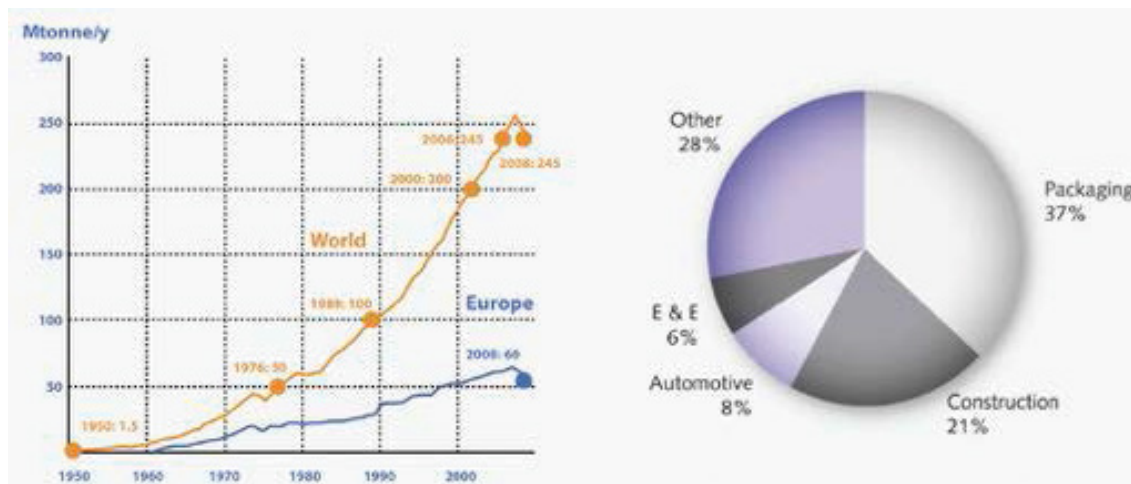
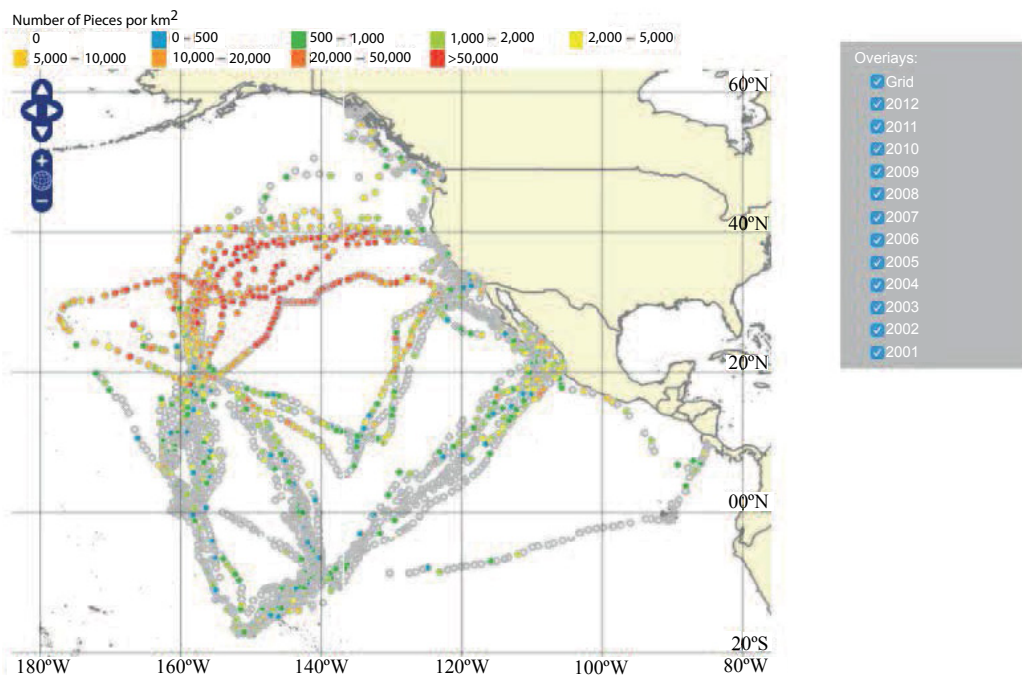


Figure 1: World plastics production 1950-2008. From the compelling facts about plastic, Plastics-Europe [141].

East Pacific

Click on the dates in the right hand side panel to show/hide samples.



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Figure 2: Distribution of microplastics in the western North Pacific, 2001-2012. Sea Education Centre, Woods Hole, MA (downloaded from: http://onsharedocean.org/open_ocean/pollution/floating_plastics).

degradation nature of the debris occurring in small and heterogeneous assemblages. It is not possible to observe the microplastic particles that float below the surface of the sea-water by flight observations or satellite and there is no accurate data estimating the global plastic inputs into the ocean and the parts that sink to the ocean floor [1]. The geographical coverage of microplastics is growing on a yearly basis. Most of the microplastic surveys have been conducted in the Northern Hemisphere and were conducted on the sea-surface. There is strong evidence that low-density microplastics such as Poly-propylene (PP),

Polyethylene (PP) and Poly-Styrene (PS) predominate the oceanic surface [18,19]. Microplastics at the sea surface have also been reported in the coastal ocean [20,21], the open ocean [22-24] and also in enclosed and semi-closed seas [25,26] and South China [27]. Floating microplastics are best sampled in the North Atlantic and Pacific oceans and in the Mediterranean Seas due to their widespread distribution and concentration in those regions as shown in Figure 2 [5]. Recently, efforts have been made to estimate and quantify surface plastic on a global scale [28,29]. Furthermore, microplastics have also been reported on

beaches at numerous locations globally [4,30]. Most studies conducted were on the surface sediments, some have also taken samples below the surface sediments [31]. Van Cauwenberghe et al. [32] conducted and reported microplastics occurrence in the deep sea sediments. High density microplastics such as Poly-Vinyl Chloride (PVC), Poly-Esters (PES) and Poly-Amide (PA) are likely to be found in largest quantities in the benthos and determining their magnitude is hindered by high cost of sampling [33].

Based on the spatial and temporal trends, the concentration of floating microplastics in the ocean is increasing over time as a result of increased plastic production, use and inefficient waste disposal management since the 1980s. For-instance, Goldstein et al. [34] reported two-order of magnitude increase of floating microplastics in the Eastern North Pacific between 1999 and 2010.

Attributes of Microplastics in the Marine Environment

Although, many different types of plastic are produced worldwide, the market is mostly dominated by 6 classes of plastics which include: Polyethylene (PE), Polypropylene (PP), Polyvinyl Chloride (PVC), Polystyrene (PS), Poly-Urethane (PUR), and Polyethylene Terephthalate (PET) [5]. Plastics originate from fossil fuels but biomass can also be used as feedback. Figures 3 and 4 show the production and sources of most artificial and natural polymers while Table 1 shows their common applications:

Microplastics encounter in the marine matrices are broadly

classified into 2 types; 1) Primary Microplastics and 2) Secondary Microplastics.

1. Primary microplastics are originally and intentionally manufactured in the size range of 1 nm to 5 mm and have applications in personal care products like toothpaste, shower gel, scrubs, cosmetics, air-blasting [35].
2. Secondary microplastics result from the breakdown of large plastic items, e.g from fishing gears, ships, aquaculture, recreational activities, transport of plastic products into finer particles [5,36,37]. The formation of microplastics in the ocean

Resin Types	Common Applications	Specific Gravity
Polyethylene	Plastic bags, Storage containers	0.91-0.95
Polypropylene	Rope, bottle caps, gear, Strapping	0.90-0.92
Polystyrene (expanded)	Cool boxes, floats, cups	0.01-1.05
Polystyrene	Utensils, Containers	1.04-1.09
Polyvinyl Chloride	Film pipe, Containers	1.16-1.30
Polyamide or Nylon	Fishing Nets, Rope	1.15-1.15
Poly (ethylene-terephthalate)	Bottles, Strapping	1.34-1.39
Polyester Resin + glass-fibre	Textiles, boats	>1.35
Cellulose Acetate	Cigarette-fibre	1.22-1.24

Table 1: Densities and common applications of plastics in the marine environment [41].

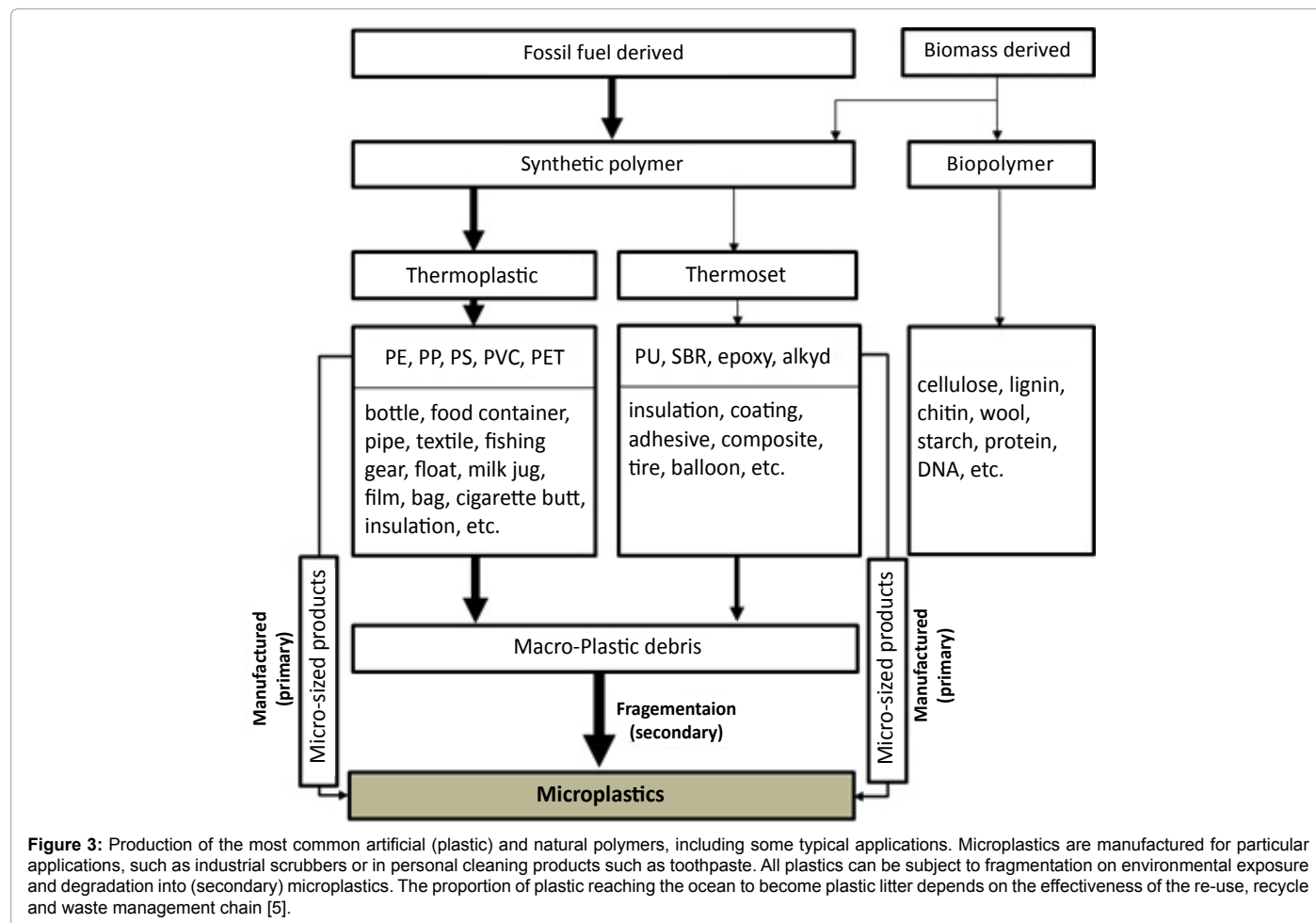


Figure 3: Production of the most common artificial (plastic) and natural polymers, including some typical applications. Microplastics are manufactured for particular applications, such as industrial scrubbers or in personal cleaning products such as toothpaste. All plastics can be subject to fragmentation on environmental exposure and degradation into (secondary) microplastics. The proportion of plastic reaching the ocean to become plastic litter depends on the effectiveness of the re-use, recycle and waste management chain [5].

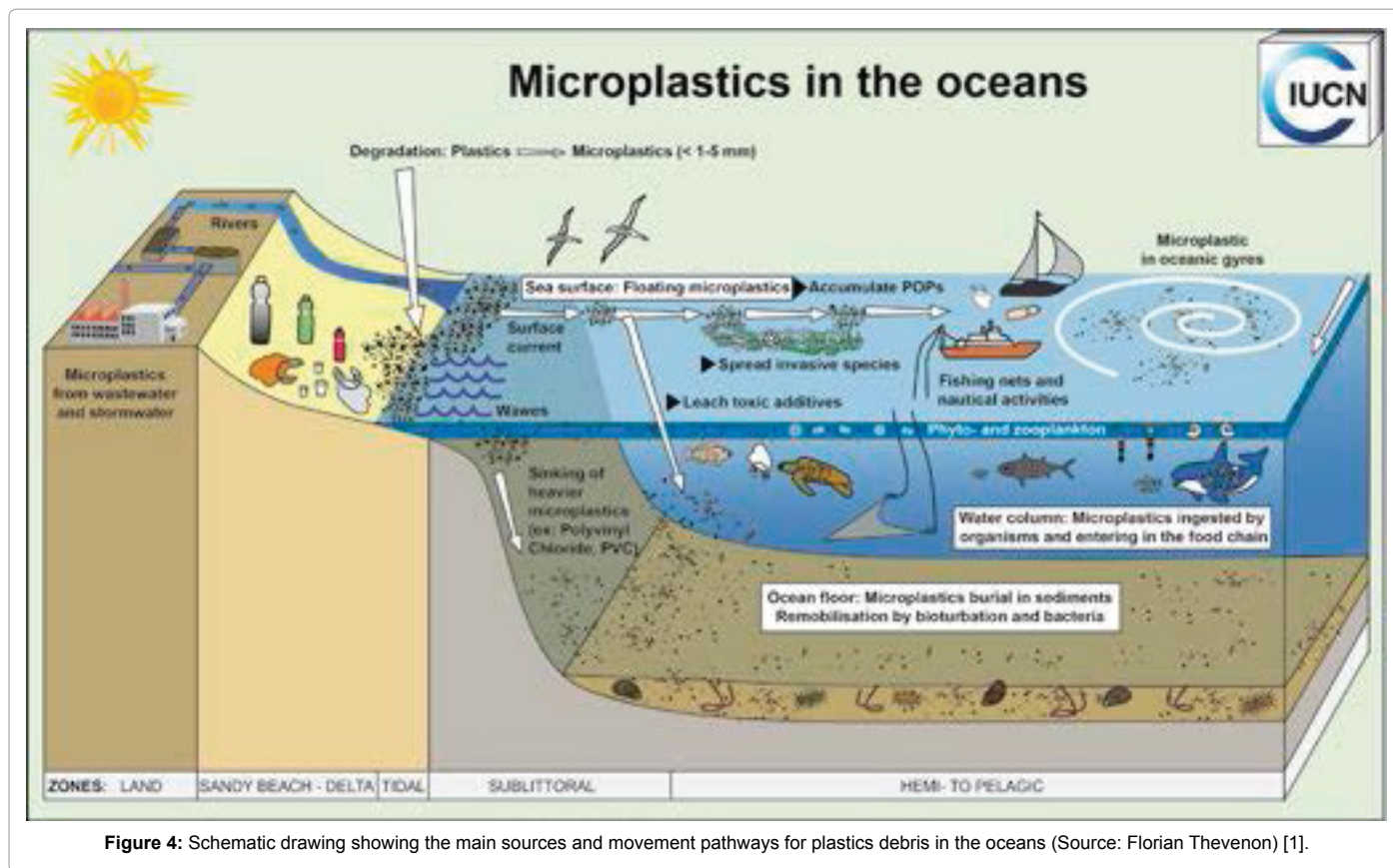


Figure 4: Schematic drawing showing the main sources and movement pathways for plastics debris in the oceans (Source: Florian Thevenon) [1].

is greatly influenced by a combination of environmental factors such as (1) solar ultra-violet radiation that facilitates oxidative degradation of polymers [38] and causes it to lose mechanical strength (2) Mechanical abrasion such as wind, wave, ocean current, animal bite, human activity that can break the polymer further into smaller fragments. This process is called “Weathering” and tends to occur in decreasing order of plastics float in water, in the mid-water column and in the sediment.

Few plastics have the tendency to undergo complete degradation or mineralization (into carbon dioxide or methane) in the marine environment. These include plastics of aliphatic polyester, bio-polymer and some bio-derived polymer origins but the cost of production of these polymers is very high [5]. These bioplastics are synthetic polymers made from plant biomass used as feedstock and are not chemically different from synthetic polymers of fossil fuel origin. They tend to degrade under certain conditions of oxygen, light levels and microbial species [39]. Microplastics could be bio-fouled and then eventually sink to the bottom where it becomes part of the sediment or may be eaten by the benthos. If plastic does become part of the sediment, whether on the shore or sea bottom, then it is no longer available for degradation by micro-organisms as it is in the water, especially if it is buried [40]. Most commodity plastics are not bio-degraded or mineralized and tend to persist for hundreds to thousands of years (decades to centuries) in the marine environment, even longer especially in the deep sea and polar region due to their high resistance to natural degradation as seen in Figure 5 [1,33,41].

Sampling and Analytical Assessment of Microplastics

Although, the presence of plastic litter is ubiquitous in all the oceans

of the world, there are still no standardized sampling and quantification methods and common units. These impede an accurate evaluation of the fate and the effects of microplastics in the marine columns. Microplastic is widely considered as under-researched components of marine debris [20]. The problem that is yet to be resolved is how to find and recommend different reproducible analytical methods with low technology and cost effective to improve characterization, identification and quantification of plastic fragments [1]. Nevertheless, a number of sampling techniques have been developed and designed to assess the presence of microplastics in the marine matrices (water, sediment and biota) [42].

Sampling of water

Microplastics in the water column can be collected using various plankton nets of different mesh sizes to harness both the pelagic and benthic zones. Neuston or manta nets of mesh size approximately 300 micro-meters are usually towed using boats or pulled along the shores for a defined distance as seen in Figure 6. Afterwards, the net is thoroughly washed or flushed with seawater and empty into a sample jar. The quantity of microplastics trapped in the net is divided by the towed area or volume of sampled water. Alternatively, microplastic particles are separated from the plankton using conventional gravity separation techniques [43]. Bongo net and benthic trawl are another sampling devices that have been explored to sample microplastics in the mid-water and sea-bed regions respectively as shown in Table 2 [44-46]. Sample bottles and rotating drum samplers have also been utilized to sample microplastics at different depths in the water column [1]. It is expedient to note that using meshes of different apertures have tendency to produce large variations in the quantity of microplastics collected. KIMO (Kommunen Internasjonale Miljøorganisasjon),

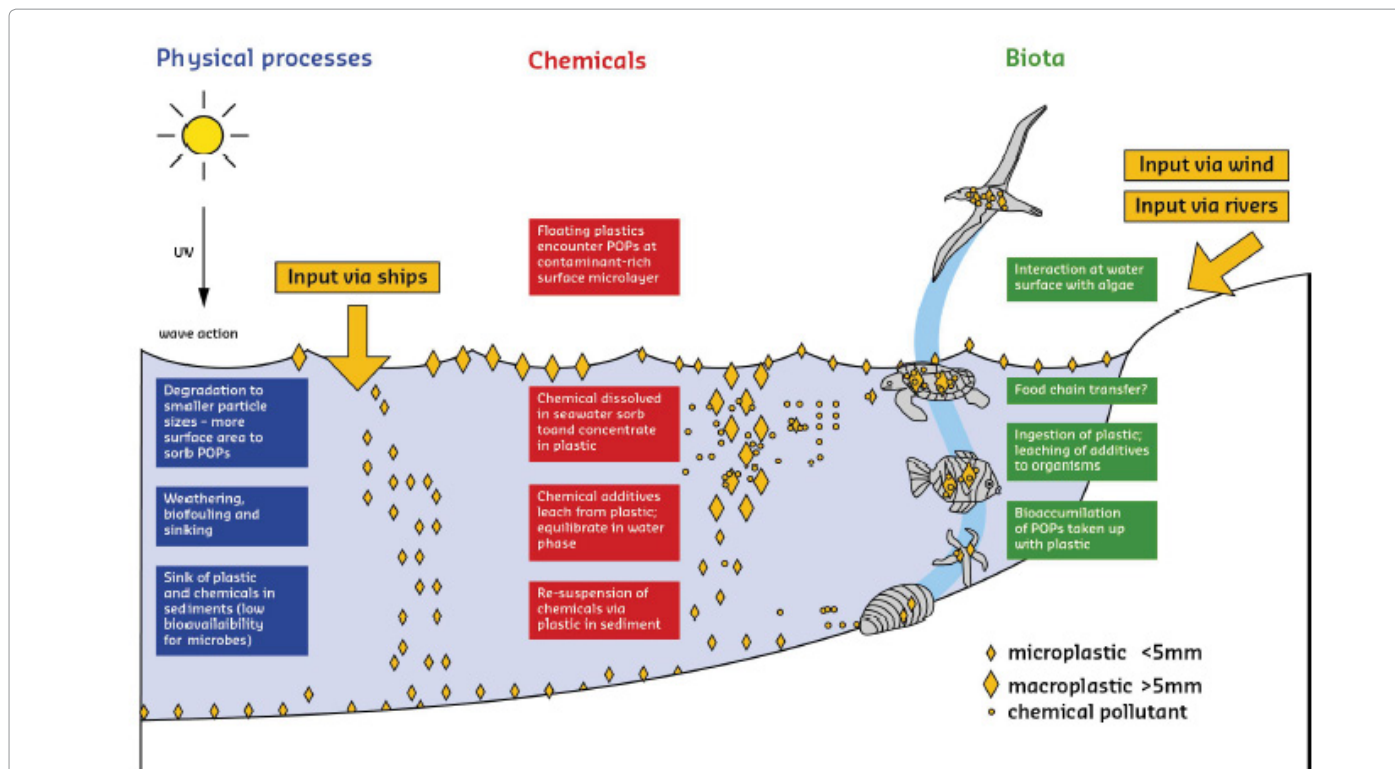


Figure 5: Sources of marine microplastics and the various physical, chemical and biological processes affecting microplastics in the marine environment [39].

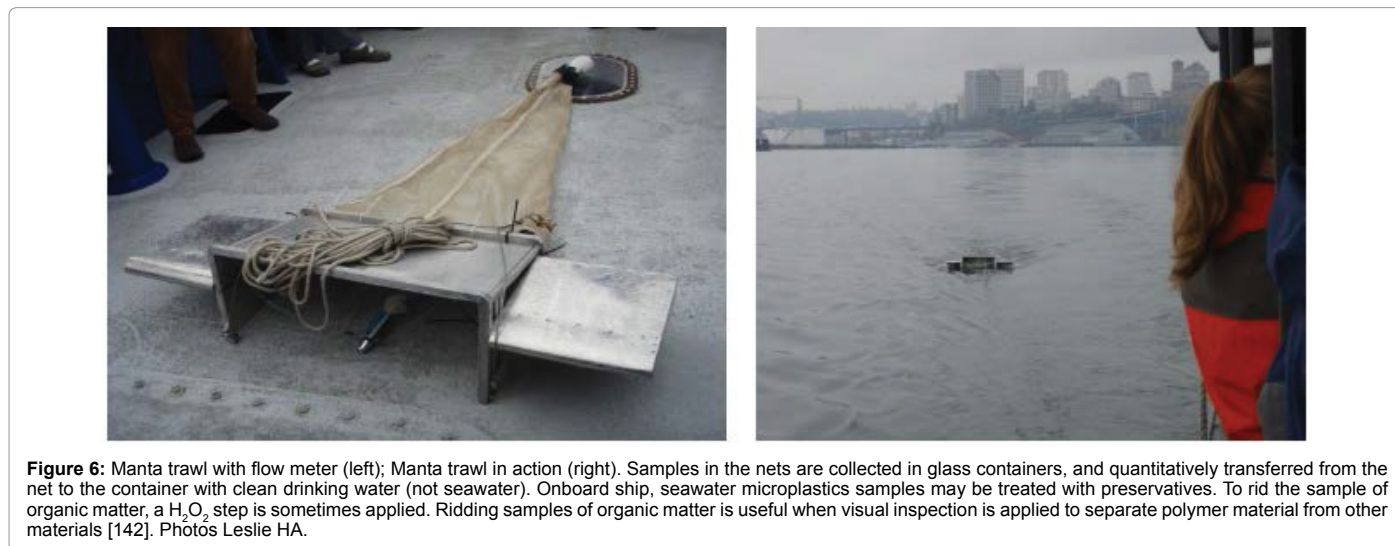


Figure 6: Manta trawl with flow meter (left); Manta trawl in action (right). Samples in the nets are collected in glass containers, and quantitatively transferred from the net to the container with clean drinking water (not seawater). Onboard ship, seawater microplastics samples may be treated with preservatives. To rid the sample of organic matter, a H₂O₂ step is sometimes applied. Ridding samples of organic matter is useful when visual inspection is applied to separate polymer material from other materials [142]. Photos Leslie HA.

Type of Sampler	Lower Size limit(µm)	Water Sampled	Reference
Mazur	330	Samples surface water with flow meter	NOAA
Regular Plankton or neuston net (Continuous plankton recorder)	330	Sample surface water at 10m depth	U. Plymouth (UK)
Algalita Manta trawl	333	Sample Surface water, Approx. 500-3000m ² per trawl	Algalita (USA), Cefas (UK)
Bongo Plankton Net	333	Samples mid-depth water column sample	Lattin et al. [129]
Epibenthic Sled	333	Sample water column near sea bottom	Lattin et al. [129]

Source: Adapted from (Leslie et al. [39]).

Table 2: Methods of sampling microplastics from seawater [39].

Sweden investigated and reported that 80 micron-meter meshes is more efficient than 450 micron-meter meshes for sampling microplastics which is 100,000 times higher in concentration of the microplastics

sieved [47]. Continuous Plankton Recorder is another tool used to determine the abundance of microplastics in the open ocean and from which long term data could be collected [45].

Sampling of sediment

This procedure allows the assessment of microplastics in the benthic sediments from beaches, estuaries and the sea-floor [31]. Grab samplers have been widely used to collect surface sediments in large quantities (several kilograms). Noren [48] collected sediments from the Swedish coastal area with the Eckman grab. The demerit of this device is that the sediments are disturbed, layers mixed up and information regarding the historical deposition could not be obtained [1]. These problems are solved using sediment corers to sample sediments without mixing up the layers [1]. Sediments are collected manually from beaches [49] and can also undergo hand sieving before further processing in the laboratory (Figure 7) [5].

Sampling of biota

Biological assessment involves examining microplastic particles consumed by the organisms especially during feeding. Stomach content analysis has been observed in several species of fish, bivalves, crustaceans and birds as seen in Figure 8 [5]. Sampling techniques of the biota depend on the type of movement performed by the animal in question i.e whether it is sedentary/sessile, mobile, fast or slow runners. Vandermeersch et al. [50] collected Hotspot mussel (*Mytilus*

galloprovincialis) by hand from three European estuaries in the coastal areas of Portugal, Sacca di Goro, Italy and Fangar Bay in Spain prior to microplastic analysis. Sampling of birds depends on the recovery of dead organisms (carcass) at shorelines or coastal nestling sites. Analysis of recovered carcasses of the northern Fulmar operates in the North Sea for monitoring and providing ecological quality based on the assessment of its stomach contents [5].

Microplastic analysis

Microplastic Analysis involves an array of steps to arrive at the identification and quantification of microplastics in the marine matrices. The lack of uniform standardized approach among regions or studies in the same region make comparisons difficult [44]. Precautions involved before analyzing microplastics are; to avoid background contamination when sampling and during extraction procedures and to remove non-plastic materials [51].

Sample preparation: This involves sieving the sediment at 150 or 500 micron-metres depending on the size range to obtain homogeneity of the material.

Separation: Microplastics in the sediment need to be separated from both organic and inorganic non-plastic particles prior to counting, weighing and identification of the polymer type. Separation is effected by density principles using salt solutions of varying densities (sodium chloride, sodium iodide, sodium polytungstate). Sediment is mixed with concentrated NaCl solution and vigorously shaken for specific period of time. The supernatant is filtered with a filtration unit and a vacuum pump. The filter (usually nitro-cellulose 0.45 micron-meter) is then dried and sealed in a petri-dish for further analysis [30,45]. The use of NaCl to separate microplastics by floatation is highly recommended as it is very cheap and eco-friendly. The setback in its usage is that it is only suitable for separating low-density plastic polymers like Polyethylene, Polypropylene and Polystyrene from non-plastic particles but unsuitable for high density plastic polymers like Polyvinyl chloride and Polyethylene terephthalate. Therefore, this problem is overcome by using Sodium Iodide (NaI) of higher density (1.6 g/cubic cm) in a subsequent step. This approach has been found to be highly economical and reduces analytical cost [52]. There have been recent advances to separate microplastics from natural organic materials in surface water sample using enzymatic digest to remove planktonic organisms [53]. In a more advanced technological approach, microplastics have been more efficiently extracted from sediment based on the principle of elutriation



Figure 7: Illustration of the amount of visible microplastics found in beach sand. Photo Vethaak AD.

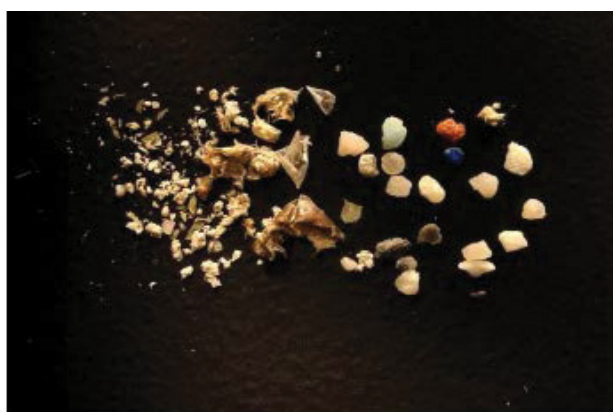


Figure 8: Lanternfish with large piece of plastic (unpassable) which broke into three pieces (left); Stomach contents – plankton on left, plastic on right (right). Reprinted with permission of Christina Boerger.

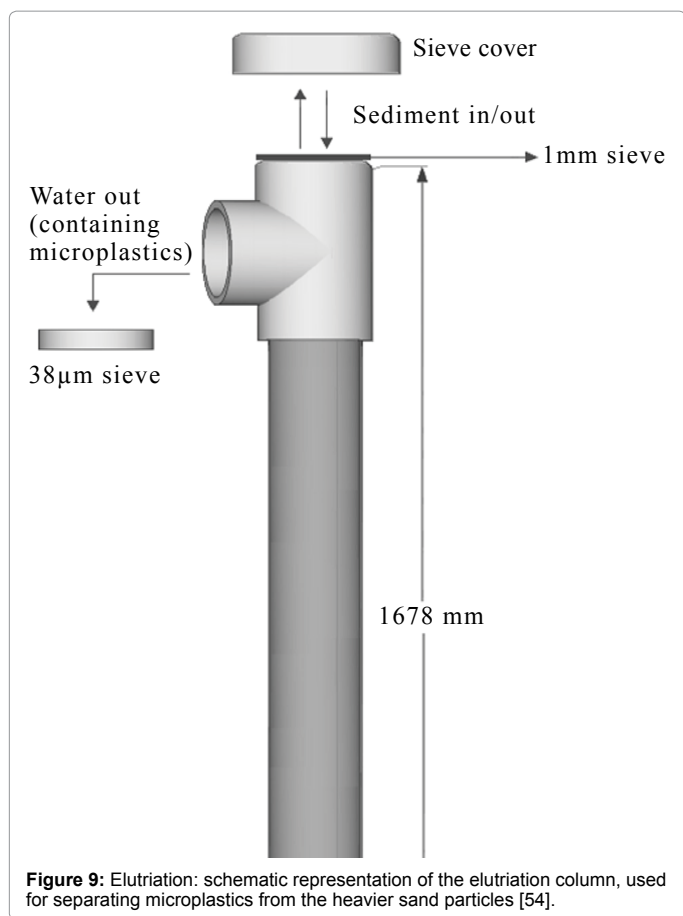


Figure 9: Elutriation: schematic representation of the elutriation column, used for separating microplastics from the heavier sand particles [54].

which is a process of separating lighter particles from heavier ones using an upward stream of gas or liquid phase (water) [54] as shown in Figure 9.

In biological assessment, the principle of wet digestion of tissues is employed. Nitric acid or Acid mix method (combination of nitric acid and perchloric acid in the ratio of 4:1 v:v) is used separately. Both methods are highly effective to destroy or digest the tissues, reduce greasy tissue fractions and enhance extraction. After complete digestion at a regulated temperature of 60 degree centigrade in the 250 ml conical flask, the digested tissue is diluted with warm deionized water and filtered over a 5 micron-metre cellulose nitrate membrane (Whatman AE 98), the filter is dried at 40 degree Celsius for 24 hours in a petri-dish and subsequently quantified under a powerful microscope [1,50,54]. Hydrogen peroxide and sodium hydroxide could also be used for digestion and extraction.

Visual sorting under microscope is necessary to separate the microplastic fragments from non-plastic particles. Each plastic piece could be picked up with forceps and placed in graduated dish to be counted, measured, photographed and classified [21]. Digital photography enhances the morphological parameters and surface of substantial plastic particles to be computed automatically. This technique was used to measure microplastics in the sea surface of the North-east Pacific ocean [55] and the North Sea [52].

Sometimes, it might be difficult and impossible to distinguish microplastics from non-plastic particles due to decreased size observed under microscope. This problem is solved with use of spectroscopic approach. Microscopic FT-IR (Fourier Transformed – Infra Red)

and Raman Spectroscopy are the most widely used to confirm the identification of plastic and their synthetic polymers for particles in the size range <1 mm [5]. This device provides reliable results and datasets and does not give room for prior pre-sorting by hand [56].

The Impacts of Microplastics on the Marine Environment

Microplastics have both direct and indirect harmful effects on the marine biota. Although, the threats posed by plastic pollution on the living resources continue to gain recognition worldwide, the effects on marine organisms, food webs, community structure and ecosystems are still poorly understood [1,57]. A study by Goldberg [58] argues that the deleterious effect of microplastics on marine life is on the rise. The threat to marine life is due to mechanical or chemical effects after the ingestion of microplastic particles. The size of ingested plastic materials is related to the body size of the organism [44,59] and ontogenetic phase [60,61]. The degree of impacts is proportional to the size, shape and amount of the ingested items and other factors which are behavioral, physiological and geographical, foraging strategies and diet [62-64].

The physical effects of microplastics ingestion

A number of field studies have revealed that microplastic particles are ingested by a wide variety of biota from all oceanic regions; planktivorous fish from North Pacific Gyre [65], mussel from Belgian coastal waters [66], harbor seals from the North Sea [67], Fulmar from the North Sea [68], Whales [69]. It was discovered that a good number of these animals tend to mistake plastic wastes for their potential prey items which they ingest accidentally or voluntarily by feeding on lower trophic organisms that have themselves consumed microplastics [35,70]. Albatrosses may take up red plastic residues for squids and ingest them unknowingly [1]. As a consequence, some obstructions/blockage/clogging of intestinal tract or digestive organs occur and impede the organisms from taking in more food resources or diminish their feeding stimulus (pseudo-satiation) [18,71]. This can lead to starvation. For instance, Eriksson and Burton [72] reported that Fur seals tend to ingest and bio-accumulate plastic debris by eating pelagic fish species that have already ingested plastic particles during feeding. Other harmful effects reported are; adsorption of the microplastics on the organism's surface, lowered steroid hormone level, delayed ovulation, reproductive failure, internal injuries like gut perforations, toxin introduction, delayed growth and death [15,18,73-78]. Spear et al. [79] provided evidence that the higher the number of plastic particles ingested; the worse the physical condition (body weight) is in seabirds from the tropical Pacific. On the other hand, microplastics can also alter the physical conditions of the marine habitats. On sandy beaches, they can affect the permeability and temperature of the sediments when they settle on the matrix with consequential effect for fauna which are temperature-dependent sex determination like the reptiles [80].

The chemical effects of microplastics ingestion

Microplastics contain some potentially harmful plasticizers called 'Additives' such as Bisphenol A (BPA) and di-butyl phthalates which are incorporated into the parent plastics during the manufacturing process [81] to give tensile strength or flexibility. These plastic particles also tend to adsorb and accumulate toxic materials from the surrounding seawater such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), persistent organic pollutants like DDT and heavy metals [82-86]. These chemicals are not chemically bound to the surface of the microplastics and eventually tend to leach into the surrounding environment or animal tissues when ingested [1]. Tagatz et al. [87] showed that high concentration of dibutyl

phthalates can adversely affect the macrobenthic communities that ingest the microplastic particles. Among the reported impacts include; reproductive dysfunctionality during developmental stage [88], hepatic stress in fish [89], decreased steroid level and delayed ovulation [90], endocrine disruption and mortality [68,91].

Transport of invasive species

Microplastics floating in the sea have the tendency of providing raft substrates for various epifauna and microbes such as bacteria, algae, diatoms, barnacles, hydroids, tunicates [92-94] and transporting them to areas where they were not existing before. This widens the range of introduced species into an environment where they were previously absent [95]. Zettler et al. [96] and Harshvardhan and Jha [97] reported that certain microbes called ‘Plastisphere’ colonized microplastic fragments collected in the North Subtropical Gyre and Arabian Sea in India which were detected using Scanning Electron Microscopy (SEM) and gene sequencing analyses. The invasion of these species can be detrimental to littoral, intertidal and shoreline ecosystems [98,99]. Gregory [100] argued that not all the species that are transported will necessarily prove harmful to their new host environment.

Social and economic effects

It has been shown that when the condition of natural asset like the ocean is altered by plastic pollution, it would influence the socio-economic systems by changing the environmental quality for future generations as seen in Table 3 [101] and results in health implications [88]. The ingestion of microplastics by marine species (fish) from the North Pacific ocean could impact the fishing industries in the future [102]. The accumulation of microplastics along the food chain as in fish and shell-fish like mollusks, crustaceans could pose a threat to the food safety and generate serious health implications on final human consumers through their diet [103]. Exposure of human population to Bisphenol A is associated with heart diseases, diabetes, alterations in circulating hormonal levels [104,105].

Possible Management Strategies to the Problems of Microplastics

The intricacy and rising scale of the marine plastic pollution issue is too large for any single agency or country to resolve [106]. Therefore, it is imperative to integrate and harmonize several measures (management, regulatory, technical and operational tools) at local, national, regional and international levels to address and tackle the problem [18].

Legislation

The most important legislation that is in place addressing the problem of marine pollution is the 1978 Protocol to the International Convention for the Preservation of Pollution from Ships (MARPOL) which forbids or bans all vessels to dispose their waste of plastic origin into the marine environment [107]. The Annex V of MARPOL is the

key international authority controlling ships at sea source of marine plastic debris [108]. Although, 79 countries have so far ratified the Annex V [109], the signatory countries are implored to fully implement the convention. Furthermore, in 2012, 64 countries and the European Union adopted the Manila Declaration with the aim of implementing United Nations Global Program of Action for the Protection of the Marine Environment from land-s-based sources. The signatories of this declaration also agreed to formulate Global Partnership on Marine Litter (GPML) whose main goal is to include sea-based sources of marine debris [1]. The most challenging aspect confronting legislation as a mitigation tool is how to enforce it in an area as vast as the world’s oceans and non-compliance of the member states to the convention [18].

Efficient waste disposal systems

Sufficient litter and recycling bins must be provided on beaches and in coastal areas. There must be regular collection and evacuation of commercial, municipal and agricultural wastes from the residential areas, streets, parks and dumping sites. Large number of incinerators must be put in place to burn plastic wastes [1].

Recycling/valorization of plastic materials

This method is regarded as the most important to reduce the negative environmental impacts of open landfills and open air burning that are commonly practiced in the developing countries to manage domestic wastes and step down the spread of ocean plastic pollution [1].

Education and public enlightenment/engagement/marine litter clean-ups

Education is a powerful tool to address the issue if it is discussed in schools. This exists in two forms; formal and informal. Formal education involves incorporating the environmental topics into the country’s educational curricular systems. Informal education involves the people or the general public engaging in volunteering projects and learning such as beach clean-ups, campaigns, seminars, rally [5]. Harvesting of plastic litters and microplastics from the marine environment are costly operations but engaging volunteers in clean-up activities can help reduce costs (although the time of volunteers also has an economic value) and improve awareness [110]. For instance, Ocean-Conservancy [111] reported that over 650,000 participants worldwide engaged in beach clean-up day in 2013 across 92 countries.

Integration and harmonization of trans-disciplinary

To actualize the implementation of action plans to reduce the input of plastics into the marine environment around the world, there is urgent need to involve different stake-holders involving plastic industries, fishing industries, food industries, tourism, shipping companies, NGOs, community, local authorities, national, regional

Sector	Impacts of marine litter	Estimated Cost
Fishing	Marine litter can lead to the loss of output or loss of value in the sales of certain types of seafood or fish	The loss of marketable lobster due to abandoned or lost fishing gear is estimated to lead to a global loss of US\$250 million per year. Microplastics are estimated to lead to a loss of up to 0.7% of annual income every year for the UK Aquaculture sector
Shipping	Plastic debris can foul ship propulsion equipment, disrupting operations, requiring clean-up, repair and rescue efforts, loss of life injury	In 2008, 286 rescues of vessels with fouled propellers in UK waters were carried out at a cost of between €830,000 and €2,189,000. Cost of removing litter and addressing damage in the Scottish aquaculture industry is estimated at €155,549/year
Tourism	Polluted beaches can discourage visitors from certain beaches, leading to loss of revenues for the tourism sector.	In Goeje Island (Republic of Korea), marine debris led to loss of revenue from tourist of between €29-37 million in 2011. In the Asia Pacific Economic Community (APEC) region, marine debris is estimated to cost the tourism sector approximately US\$622 million/year

Table 3: Potential economic impacts and costs of marine litter Source: Watkins et al. [110].

and international parastatals, in addressing socio-economic and environmental problems associated with plastic pollution and also in decision making process [1].

Innovating bio-degradable plastics and other alternatives

Advanced technology needs to be developed to mass produce eco-friendly biodegradable and photo-degradable plastics [112,113] at low cost that can be affordable by the public. Although, the effects of final degradation of the products are not yet known, this may portend more dangers [57,112]. Another way of reducing plastic is to use products made from other alternative materials such as stainless steel (drink containers), aluminium, glass e.g straws or cotton e.g shopping bags but their effectiveness are yet to be assessed [114].

Discussion

For decades, scientific interest has grown and expanded knowledge for microplastics but some fundamental questions and issues still remain pending and unresolved [42]. There are discrepancies in the sample strategies, equipment, procedures and assessors that might influence the results of microplastics quantification unknowingly [50]. These differences include; the use of filters of different pore sizes for retaining particles, this could lead to results obtained being underestimated and biased. Diverse digestion methods are described in the literature as shown in Figure 10 and choosing one technique singly could influence the estimation. Claessens et al. [54] and the International Council for the Exploration of the Sea (ICES, 2015) reported that the Acid mix method of digestion tends to be highly detrimental and destructive to microplastics of Nylon origin. Similarly, Cole et al. [53] was of the opinion that alkaline treatment (the use of NaOH, KOH which is an alternative approach) causes damage and discoloration of microplastics beyond recognition. Nuelle et al. [52] supported the idea by demonstrating that using oxidizing agent (Hydrogen peroxide) treatment of 35% could result in the size reduction of the plastic

particles of polyethylene and polypropylene and also unable to remove all the biological materials from completely from the mixture. The use of spectrometry for direct identification of microplastics is not reliable as it can be hindered by the presence of pigments [103]. To date, there is no unified and agreed scientific method for estimating and quantifying microplastics. Therefore, there is a need for a standardized approach to be developed for quantifying microplastic iin a reproducible and science-based manner [50].

A multi-disciplinary approach can help to some extent to provide solutions to the problems of microplastics because knowledge and ideas of multiple experts from different fields are harnessed to arrive at a joint research question and focus on the area of concern for the conservation of biota and habitats [115-118]. There is need to involve disciplines that can understand the economic and social barriers and effect change behavior and markets [119-121] and evaluate the benefits.

Conclusion and Recommendation

To solve the problems posed by plastic pollution, there is an urgent need to identify the various sources and transport mechanisms involved which will guide and help us to close the tap, develop mitigation strategies and clean-up programs that are highly efficient on a long term basis [1,122-127]. At present, the environmental fate, bioaccumulation and quantification of microplastics still remain vague. Therefore, it is mandatory and useful to develop a common standardized and harmonized methods and units so as to make comparisons feasible [50]. There is a critical need to understand the impacts of chemicals associated with plastic waste on the environment and human health and what cost-effective measures should be put in place to address the issue [128-133]. For example, there is little information on the actual health risks associated with ingestion of microplastics – both to marine species and to human consumers [110]. All sectors of the community (the general public, the scientific organizations and NGOs) have a key and crucial role to play [134-139]. There is no one perfect solution

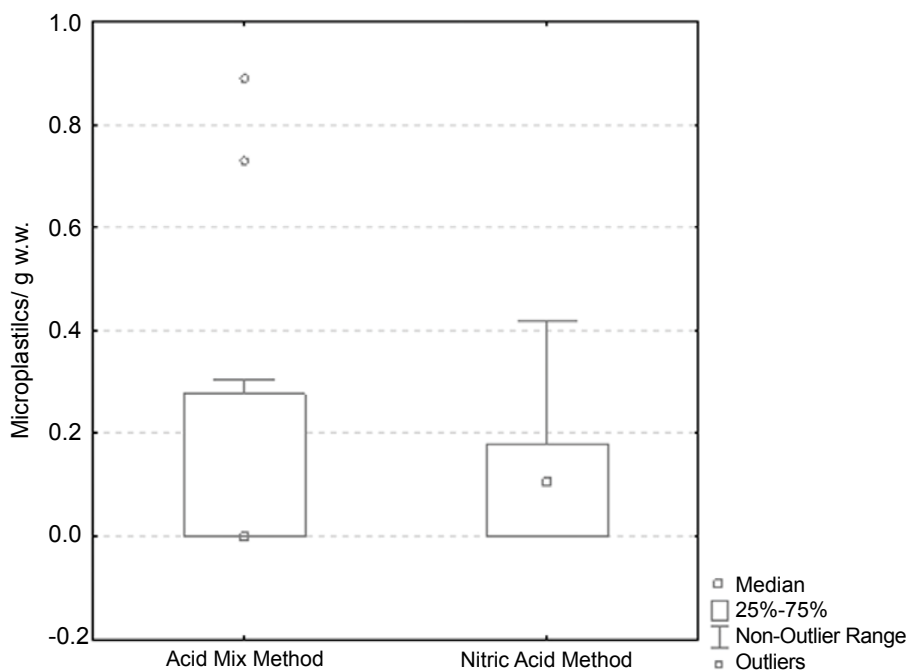


Figure 10: Total number of microplastics in hotspot mussels (three estuaries together) evaluated by the Acid mix Method and the Nitric acid [50].

to the issue [5]. All hands must be on deck (policy formulation and implementation, surveillance and monitoring operations, adherence to the existing laws and regulation) and the combination of different strategies (change in producer's product design, provision of waste management infrastructure and wastewater treatment facilities, economic incentives, bans on plastic bags, plastic blasting in shipyards, awareness raising activities among consumers to help them reduce their consumption of plastic bags and cosmetic products containing microbeads, fishing for plastic litter) must be harnessed to resolve the issue [110]. It is time to take local, regional and global level actions and work synergistically to prevent or control the entry of plastics into the oceans [1]. Above all, understanding risk and benefit perception of the people would go a long way to influence their behaviors and acceptability of regulatory measures [140]. Thinking globally and acting locally would go a long way to reduce the environmental threats drastically [18].

Acknowledgements

I would like to thank Professor (Dr) Tilmann Harder of the Marine Chemistry Department, University of Bremen, Germany for proof-reading, reviewing, criticisms, insights, inputs, corrections/adjustments and suggestions made for the successful write up of this paper. Special thanks to German Academic Exchange Service (DAAD) for their financial support.

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