Journal of Pollution Effects & Control
Ogunola and Palanisami, J Pollut Eff Cont 2016, 4:2
http://dx.doi.org/10.4172/2375-4397.1000161
Review Article
Open Access

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

Ogunola Oluniyi Solomon[1]* and Thava Palanisami[2]

[1]*International Studies in Aquatic Tropical Ecology, University of Bremen, Germany*
[2]*Global Centre for Environmental Remediation, University of Newcastle, Adelaide, Australia*

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 degrades 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

***Corresponding author:** Ogunola Oluniyi Solomon, International Studies in Aquatic Tropical Ecology, University of Bremen, Germany, Tel: +4915217802485; E-mail: solomonunilag@yahoo.com

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

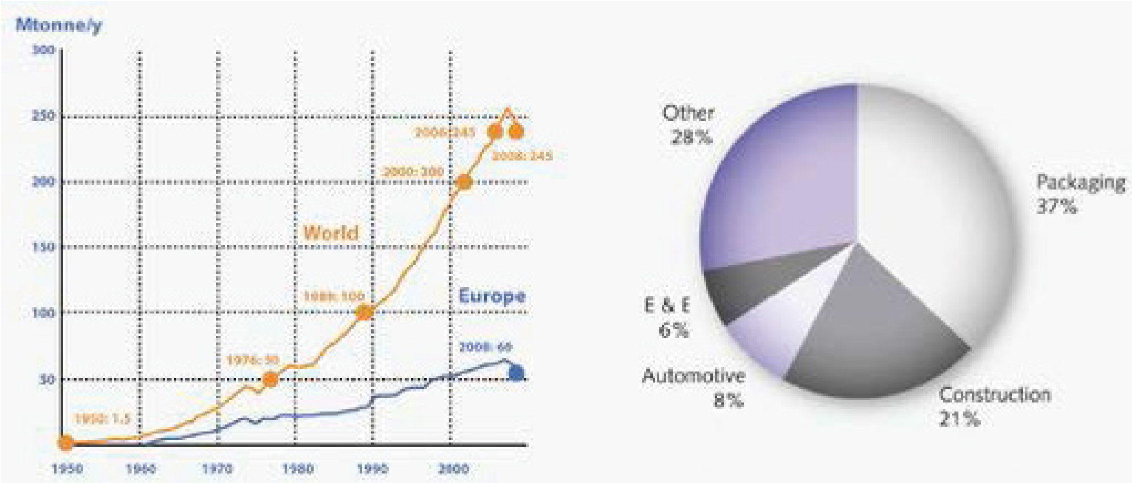

Figure 1: World plastics production 1950-2008. From the compelling facts about plastic, Plastics-Europe [141].

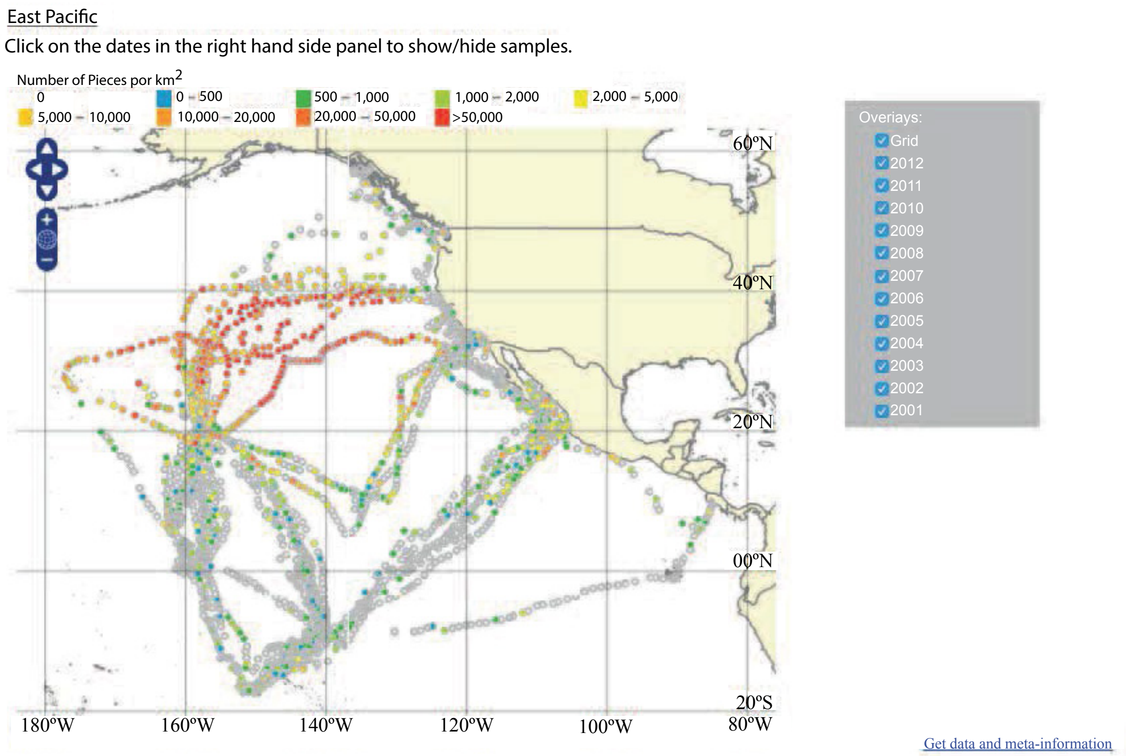

Figure 2: Distribution of microplastics in the western North Pacific, 2001-2012. Sea Education Centre, Woods Hole, MA (downloaded from: http://onesharedocean.org/open_ocean/pollution/floating_plastics).

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 microplatics 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].

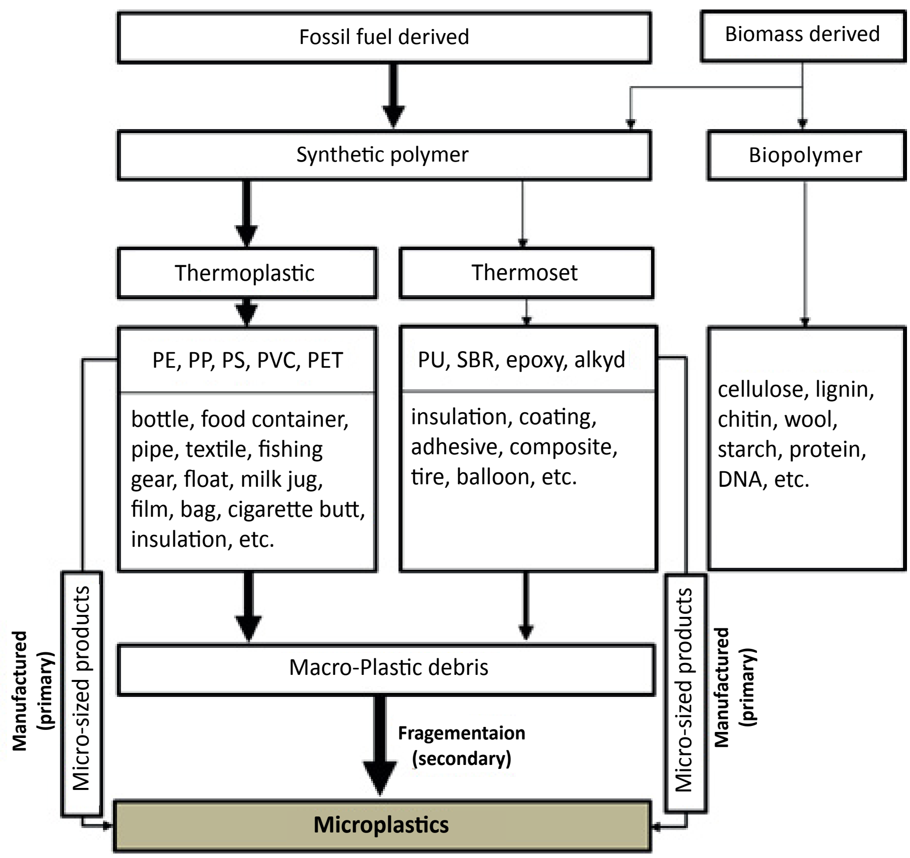

Figure 3: Production of the most common artificial (plastic) and natural polymers, including some typical applications. Microplastics are manufactured for particular applications, such as industrial scrubbers or in personal cleaning products such as toothpaste. All plastics can be subject to fragmentation 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].

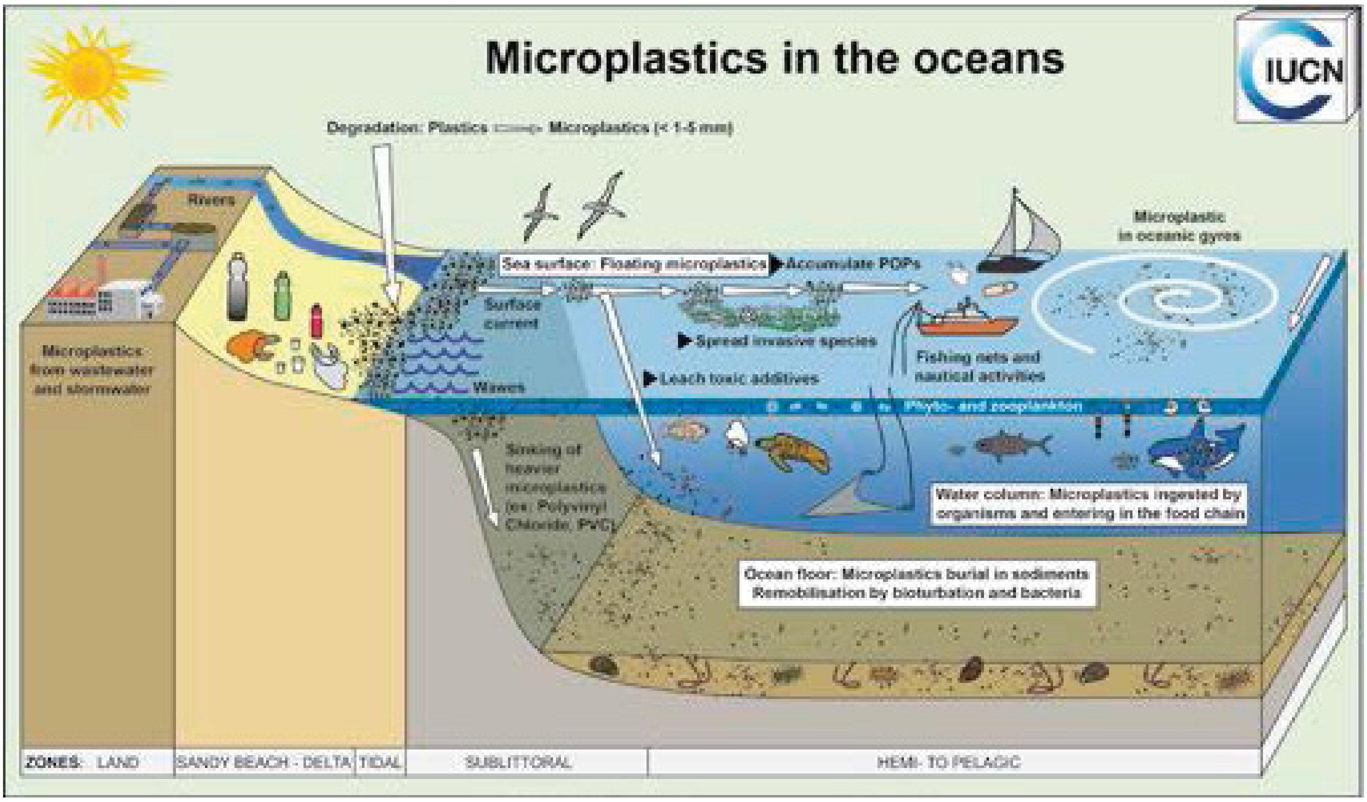

Figure 4: Schematic drawing showing the main sources and movement pathways for plastics debris in the oceans (Source: Florian Thevenon) [1].

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 loose 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 (Kommunenes Internasjonale Miljoorganisasjon),

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

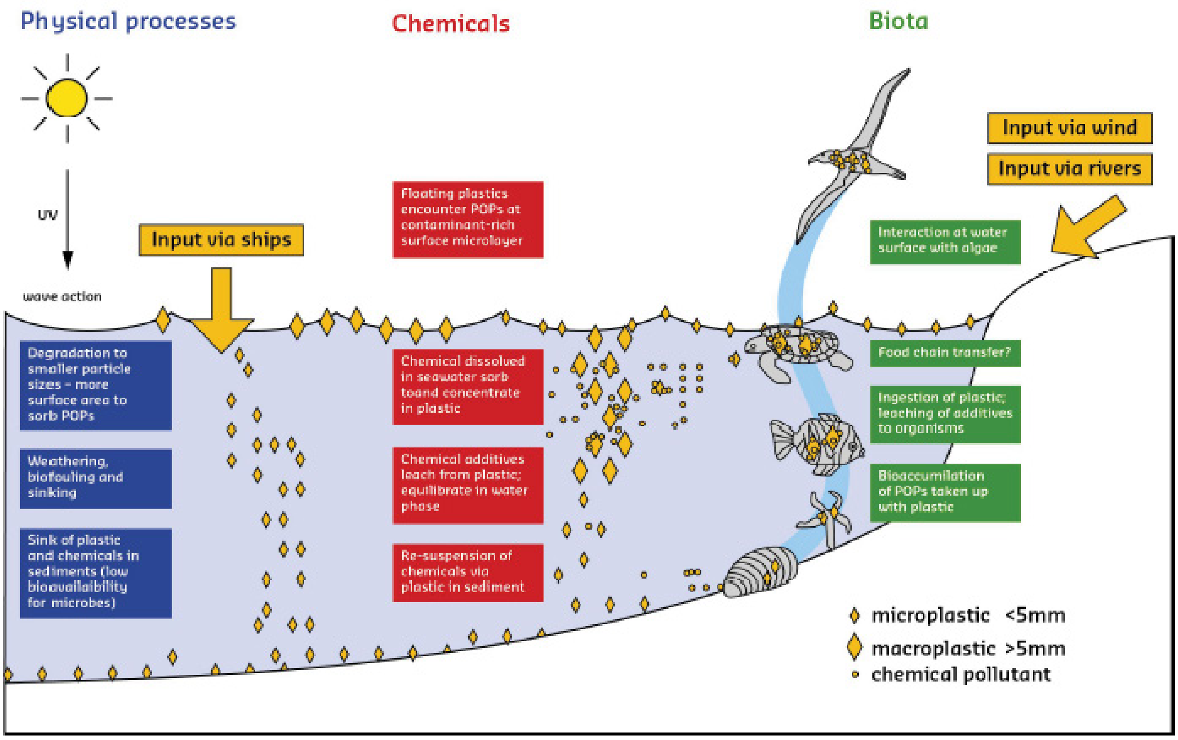

Figure 5: Sources of marine microplastics and the various physical, chemical and biological processes affecting microplastics in the marine environment [39].

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 H_2O_2 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].

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

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 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.

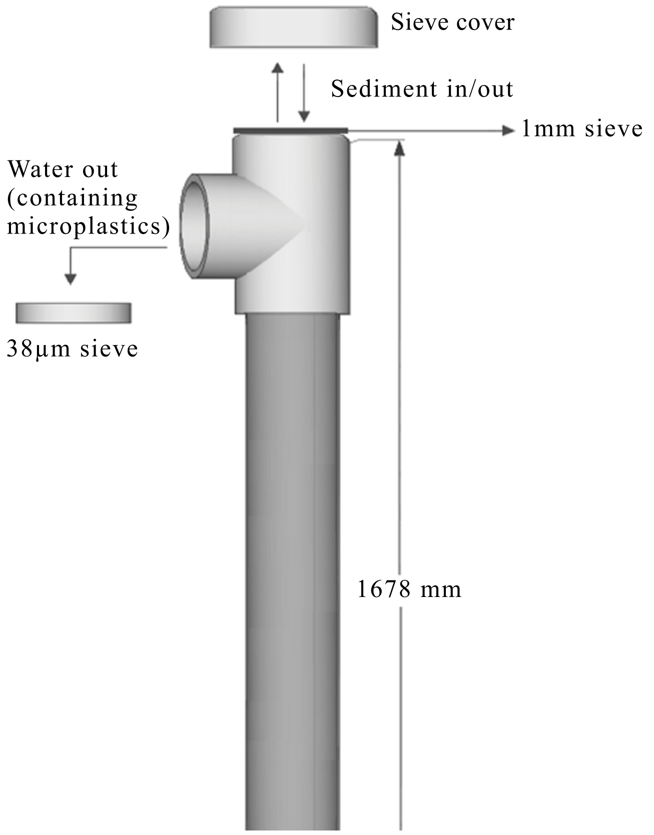

Figure 9: Elutriation: schematic representation of the elutriation column, used for separating microplastics from the heavier sand particles [54].

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 of 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].

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

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

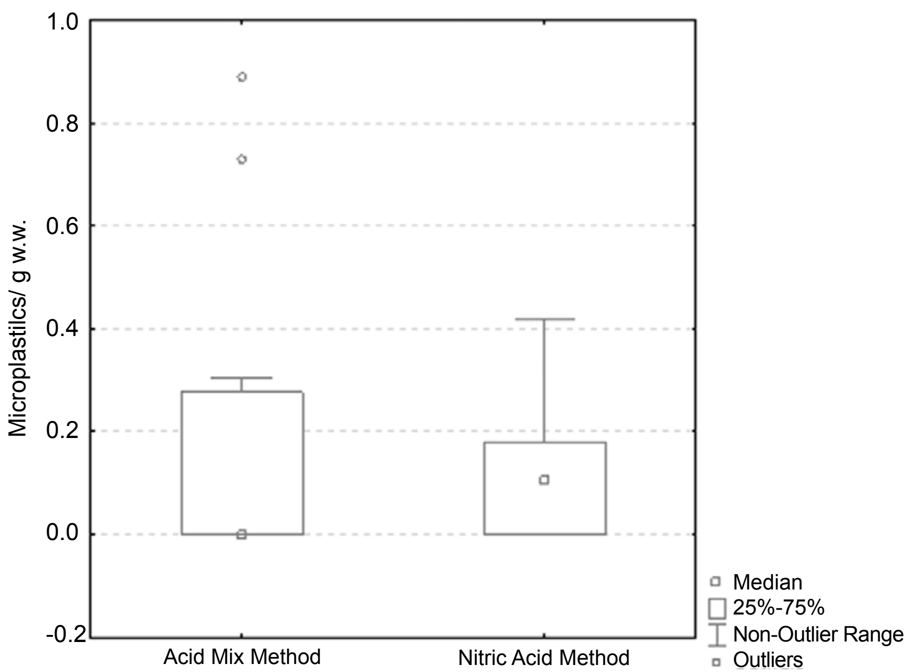

Figure 10: Total number of microplastics in hotspot mussels (three estuaries together) evaluated by the Acid mix Method and the Nitric acid [50].

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.

References

1. Thevenon F, Carroll C, Sousa J (2014) Plastic Debris in the Ocean: Characterization of Marine Plastics and their Environmental Impacts, Situation Analysis Report. Gland, Switzerland, IUCN 52.
2. Stefatos A, Charalampakis M, Papatheodorou G, Ferentinos G (1999) Marine debris on the seafloor of the Mediterranean Sea: examples from two enclosed gulfs in Western Greece. Marine Pollution Bulletin 36: 389-393.
3. Plastics-Europe (2010) Plastics-The Facts 2010.
4. Browne MA, Crump P, Niven SJ, Teuten EL, Tonkin A, et al. (2011) Accumulations of microplastic on shorelines worldwide: sources and sinks. Environ SciTechnol 45: 9175-9179.
5. Gesamp (2015) Sources, Fate and effects of Microplastics in the Marine Environment: A global Assessment. (Kershaw PJ (ed.) (IMO7FAO7UNESCO-IOC7UNIDO7WMO7IAEA7UN7UNEP7UNDP Joint Group Experts on the Scientific Aspects of Marine Envtal. Protection) 96.
6. Cawthorn M (1989) Impacts of marine debris on wildlife in New Zealand coastal waters. In: Proceedings of Marine Debris in New Zealand's Coastal Waters Workshop, 9 March 1989, Wellington, New Zealand. Department of Conservation, Wellington, New Zealand pp: 5-6.
7. DOC (1990) Department of Conservation. Marine Debris. Wellington, New Zealand.
8. Shehada A, Land M (2014) What are the effects of plastic particles on growth and mortality of marine organism?. PS5 Pilot Study.
9. Plastics-Europe (2009) The Compelling Facts About Plastics, Brussels.
10. Laist DW (1987) Overview of the biological effects of lost and discarded plastic debris in the marine environment. Marine Pollution Bulletin 18: 319-326.
11. Goldberg ED (1997) Plasticizing the seafloor: an overview. Environmental Technology 18: 195-202.
12. Ivar do Sul JA, Costa MF, Barletta M, Cysneiros FJA (2013) 'Pelagic microplastics around an archipelago of the Equatorial Atlantic'. Mar Pollut Bull 75: 305-309.
13. Wright SL, Rowe D, Thompson RC, Galloway TS (2013a) Microplastic ingestion decreases energy reserves in marine worms. Current Biology 23: R1031-R1033.
14. Wright SL, Thompson RC, Galloway TS (2013b) The physical impacts of microplastics on marine organisms: A review. Environmental Pollution 178: 483-492.
15. Tanaka K, Takada H, Yamashita R, Mizukawa K, Fukuwaka MA, et al. (2013) Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. Mar Pollut Bull 69: 219-222.
16. Gordon M (2006) Eliminating land-based discharges of marine debris in California: A plan of action from the Plastic Debris Project. Prepared by the California Coastal Commission.
17. Jayasiri HB, Purushothaman CS, Vennila A (2013) Plastic litter accumulation on high-water strandline of urban beaches in Mumbai, India. Environ Monit Assess 185: 7709-7719.
18. Derraik JGB (2002) The pollution of the marine environment by plastic debris: a review. Marine Pollution Bulletin 44: 842-852.
19. Gregory MR (1996) Plastic "scrubbers" in hand cleansers: a further (and minor) source for marine pollution identified. Marine Pollution Bulletin 32: 867-871.
20. Doyle MJ, Watson W, Bowlin NM, Sheavly SB (2011) Plastic particles in coastal pelagic ecosystems of the Northeast Pacific ocean. Marine Environmental Research 71: 41-52.
21. Reisser J, Shaw J, Wilcox C, Hardesty BD, Proietti M, et al. (2013) Marine Plastic Pollution in Waters around Australia: Characteristics, Concentrations, and Pathways. PLoS ONE 8: e80466.
22. Law KL, Moret-Ferguson S, Maximenko NA, Proskurowski G, Peacock EE, et al. (2010) Plastic accumulation in the North Atlantic subtropical gyre. Science 1185-1188.
23. Goldstein MC, Rosenberg M, Cheng L (2012) Increased oceanic microplastic debris enhances oviposition in anendemic pelagic insect. Biol Lett 8: 817-820.
24. Eriksen M, Maximenko N, Thiel M, Cummins A, Lattin G, et al. (2013) Plastic pollution in the South Pacific subtropical gyre. Marine Pollution Bulletin 68: 71-76.
25. Collignon A, Hecq JH, Galgani F, Voisin P, Collard F, et al. (2012) Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. Marine Pollution Bulletin 64: 861-864.
26. Yamashita R, Tanimura A (2007) 'Floating plastic in the Kuroshio Current area, western North Pacific Ocean'. Marine Pollution Bulletin 54: 485-488.
27. Zhou P, Huang C, Fang H, Cai W, Li D, et al. (2011) 'The abundance, composition and sources of marine debris in coastal seawaters or beaches around the northern South China Sea (China)'. Mar Pollut Bull 62: 1998-2007.
28. Cózar A, Echevarría F, González-Gordillo JI, Irigoien X, Úbeda B, et al. (2014) Plastic debris in the open ocean. Proceedings of the National Academy of Sciences of the United States of America 111: 10239-10244.
29. Yamashita R, Takada H, Fukuwaka MA, Watanuki Y (2011) Physical and chemical effects of ingested plastic debris on short-tailed shearwaters, Puffinus tenuirostris, in the North Pacific Ocean. Mar Pollut Bull 62: 2845-2849.
30. Hidalgo-Ruz V, Gutow L, Thompson RC, Thiel M (2012) Microplastics in the marine environment: a review of the methods used for identification and quantification. Environ Sci Technol 46: 3060-3075.
31. Claessens M, Meester SD, Landuyt LV, Clerck KD, Janssen CR (2011) Occurrence and distribution of microplastics in marine sediments along the Belgian coast. Mar Pollut Bull 62: 2199-2204.
32. Van Cauwenberghe L, Vanreusel A, Mees J, Janssen CR (2013c) 'Microplastic pollution in deep-sea sediments'. Environmental Pollution 182: 495-499.
33. Barnes DKA, Galgani F, Thompson RC, Barlaz M (2009) Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 1985-1998.
34. Goldstein MC, Titmus AJ, Ford M (2013) Scales of spatial heterogeneity of plastic marine debris in the northeast Pacific Ocean. PLOS ONE 8: e80020.
35. Fendall LS, Sewell MA (2009) Contributing to marine pollution by washing your face: Microplastics in facial cleansers. Mar Pollut Bull 58: 1225-1228.
36. Astudillo JC, Bravo M, Dumont CP, Thiel M (2009) Detached aquaculture buoys in the SE Pacific: potential dispersal vehicles for associated organisms. Aquat Biol 5: 219-223.
37. Bowmer T, Kershaw P (eds.) (2010) Proceedings of the GESA microplastic international workshop on micro-plastic particles as a vector in transporting persistent, bioaccumulating and toxic substances in the oceans. UNESCO-IOC, Paris 69.
38. Tourinho PS, do Sul JAI, Fillmann G (2010) Is marine debris ingestion still a problem for the coastal marine biota of southern Brazil? Mar Pollut Bull 60: 396-401.

39. Leslie HA, van Velzen MJM, Vethaak AD (2013) Microplastic survey of the Dutch environment. Novel data set of microplastics in North Sea sediments, treated wastewater effluents and marine biots. Amsterdam, The Netherlands: IVM Institute for Environmental Studies, Final report R-13/11.

40. Teuten EL, Rowland SJ, Galloway TS, Thompson RC (2007) Potential for plastics to transport hydrophobic contaminants. Environ SciTechnol 41: 7759-7764.

41. Andrandy AL (2011) Microplastics in the marine environment. Marine Pollution Bulletin 62: 1596-1605.

42. Cole M, Lindeque P, Halsband C, Galloway TS (2011) Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin 62: 2588-2597.

43. Collignon A, Hecq JH, Galgani F, Collard F, Goffart A (2014) Annual variation in neustonic micro- and meso-plastic particles and zooplankton in the Bay of Calvi (Mediterranean–Corsica). Marine Pollution Bulletin 79: 293-298.

44. Ryan PG, Moore CJ, van Franeker JA, Moloney CL (2009) Monitoring the abundance of plastic debris in the marine environment. Philos Trans R Soc B Biol Sci 364: 1999-2012.

45. Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, et al. (2004) Lost at sea: where is all the plastic? Science 838.

46. Browne MA, Galloway TS, Thompson RC (2010) Spatial patterns of plastic debris along estuarine shorelines. Environ Sci Technol 44: 3404-3409.

47. Lozano RL, Mouat J (2009) Marine Litter in the North-East Atlantic Region: Assessment and Priorities for Response. KIMO International.

48. Norén F (2008) Small plastic particles in coastal Swedish waters. N-Research report, commissioned by KIMO Sweden 11.

49. Dekiff JH, Remy D, Klasmeier J, Fries E (2014) Occurrence and spatial distribution of microplastics in sediments from Norderney. Environ Pollut 186: 248-256.

50. Vandermeersch G, Van Cauwenberghe L, Janssen CR, Marques A, Granby K, et al. (2015) A critical Review on Microplastic quantification in aquatic organisms. Envt Res 143: 46-55.

51. Fries E, Dekiff JH, Willmeyer J, Nuelle MT, Ebert M, et al. (2013) Identification of polymer types and additives in marine microplastic particles using pyrolysis-GC/MS and scanning electron microscopy. Environmental Science: Processes & Impacts 15: 1949-1956.

52. Nuelle MT, Dekiff JH, Remy D, Fries E (2014) A new analytical approach for monitoring microplastics in marine sediments. Environmental Pollution 184: 161-169.

53. Cole M, Lindeque P, Fileman E, Halsband C, Goodhead R, et al. (2013) Microplastic Ingestion by Zooplankton. Environ SciTechnol 47: 6646-6655.

54. Claessens M, van Cauwenberghe L, Vandegehuchte MB, Janssen CR (2013) New Techniques for the detection of microplastics in sediments and field organisms. Marine Pollution Bulletin 70: 227-233.

55. Goldstein MC, Goodwin DS (2013) Gooseneck barnacles (Lepas spp.) ingest microplastic debris in the North Pacific Subtropical Gyre. Peer J 1: e184.

56. Löder M, Gerdts G (2013) FT-IR analysis for monitoring marine microplastics, YOUMARES 4, Oldenburg.

57. Quayle DV (1992) Plastics in the marine environment: problems and solutions. Chemical Ecology 6: 69-78.

58. Goldberg ED (1995) The health of the oceans-a 1994 update. Chemical Ecology 10: 3-8.

59. Furness RW (1985) Plastic particle pollution: accumulation by Procellariiform seabirds at Scottish colonies. Marine Pollution Bulletin 16: 103-106.

60. Ramos J, Barletta M, Costa M (2012) Ingestion of nylon threads by Gerreidae while using a tropical estuary as foraging grounds. Aquat Biol 17: 29-34.

61. Dantas D, Barletta M, Ramos J, Lima A, Costa M (2013) Seasonal diet shifts and overlap between two sympatric catfishes in an estuarine nursery. Estuaries Coasts 36: 237-256.

62. Moser ML, Lee DS (1992) A fourteen-year survey of plastic ingestion by Western North Atlantic seabirds. Colonial Waterbirds 15: 83-94.

63. Laist DW (1997) Impacts of marine debris: Entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe JM, Rogers DB (eds.) Marine Debris. Sources, Impacts, Solutions. Springer-Verlag New York, Inc 99-140.

64. Vegter AC, Barletta M, Beck C, Borrero J, Burton H, et al. (2014) Global research priorities to mitigate plastic pollution impacts on marine wildlife. Endangered Species Research 25: 225-247.

65. Boerger CM, Lattin GL, Moore SL, Moore CJ (2010) Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Marine Pollution Bulletin 60: 2275-2278.

66. Van Cauwenberghe L, Claessens M, Vandegehuchte M, Janssen C (2012a) ‘Occurrence of microplastics in mussels (Mytilus edulis) and lugworms (Arenicola marina) collected along the French-Belgian-Dutch coast’. VLIZ Special Publication 55.

67. Rebolledo ELB, van Franeker JA, Jansen OE, Brasseur SMJM (2013) ‘Plastic ingestion by harbour seals (Phoca vitulina) in The Netherlands’. Mar Pollut Bull 67: 200-202.

68. Van Franeker JA, Blaize C, Danielsen J, Fairclough K, Gollan J, et al. (2011) Monitoring plastic ingestion by the northern fulmar Fulmarus glacialis in the North Sea. Environmental Pollution 159: 2609-2615.

69. De Stephanis RJ, Gimenez E, Carpinelli C, Gutierrez-Exposito, Canadas A (2013) ‘As main meal for spermwhales: Plastics debris’. Marine Pollution Bulletin 69: 206-214.

70. Browne MA, Dissanayake A, Galloway TS, Lowe DM, Thompson RC (2008) Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L.). Environ Sci Technol 42: 5026-5031.

71. Thompson RC (2006) Plastic debris in the marine environment: consequences and solutions. In: Krause JC, Nordheim H, Bräger S (eds.), Marine Nature Conservation in Europe. Federal Agency for Nature Conservation, Stralsund, Germany 107-115.

72. Eriksson C, Burton H (2003) Origins and biological accumulation of small plastic particles in fur seals from Macquarie Island. Ambio 32: 380-384.

73. Zitko V, Hanlon M (1991) Another source of pollution by plastics: skin cleansers with plastic scrubbers. Marine Pollution Bulletin 22: 41-42.

74. McCauley SJ, Bjorndal KA (1999) Conservation implications of dietary dilution from debris ingestion: sublethal effects in post-hatchling loggerhead sea turtles. Conserv Biol 13: 925-929.

75. Mader D (2006) Reptile medicine and surgery. Elsevier Inc., St Louis, MO.

76. Teuten EL, Saquing JM, Knappe DRU, Barlaz MA, Jonsson S, et al. (2009) Transport and release of chemicals from plastics to the environment and to wildlife. Philosophical Transactions of the Royal Society B: Biological Sciences 364: 2027-2045.

77. Gray H, Lattin GL, Moore CJ (2012) Incidence, mass and variety of plastics ingested by laysan (Phoebastria im -mutabilis) and black-footed albatrosses (P. nigripes) recovered as by-catch in the North Pacific Ocean. Mar Pollut Bull 64: 2190-2192.

78. Bhattacharya P, Lin S, Turner JP, Ke PC (2010) Physical adsorption of charged plastic nanoparticles affects algal photosynthesis. J Phys Chem C 114: 16556-16561.

79. Spear LB, Ainley DG, Ribic CA (1995) Incidence of plastic in seabirds from the tropical Pacific, 1984–91 –relation with distribution of species, sex, age, season, year and body-weight. Marine Environmental Research 40: 123-146.

80. Carson HS, Colbert SL, Kaylor MJ, McDermid KJ (2011) Small plastic debris changes water movement and heat transfer through beach sediments. Marine Pollution Bulletin 62: 1708-1713.

81. Meeker JD, Sathyanarayana S, Swan SH (2009) Phthalates and other additives in plastics: human exposure and associated health outcomes. Philos Trans R Soc Lond B Biol Sci 364: 2097-2113.

82. Mato Y, Isobe T, Takada H, Kanehiro H, Ohtake C, et al. (2001) Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. Environ Sci Technol 35: 318-324.

83. Ashton K, Holmes L, Turner A (2010) Association of metals with plastic production pellets in the marine environment. Mar Pollut Bull 60: 2050-2055.

84. Holmes LA, Turner A, Thompson RC (2012) Adsorption of trace metals toplastic resin pellets in the marine environment. Environ Pollut 160: 42-48.

85. Rochman CM, Hentschel BT, Teh SJ (2014a) Long-term sorption of metals is similar among plastic types: Implications for plastic debris in aquatic environments. PloS ONE 9: e85433.

86. Rochman CM, Lewison RL, Eriksen M, Allen H, Cook AM, et al. (2014b) Polybrominated diphenyl ethers (PBDEs) in fish tissue may be an indicator of plastic contamination in marine habitats. Sci Total Environ 476-477: 622-633.

87. Tagatz ME, Plaia GR, Deans CH (1986) Toxicity of dibutyl phthalate-contaminated sediment to laboratorycolonized and field-colonized estuarine benthic communities. Bull Environ Contam Toxicol 37: 141-150.

88. Talsness CE, Andrade AJM, Kuriyama SN, Taylor JA, vom Saal FS (2009) Components of plastic: experimental studies in animals and relevance for human health. Philos Trans R Soc Lond B Biol Sci 364: 2079-2096.

89. Rochman CM, Browne MA, Halpern BS, Hentschel BT, Hoh E, et al. (2013) Policy: Classify plastic waste as hazardous. Nature 494: 169-171.

90. Azzarello MY, Van Vleet ES (1987) Marine birds and plastic pollution. Marine Ecology Progress Series 37: 295-303.

91. Bouland AJ, White AE, Lonabaugh KP, Varian-Ramos CW, Cristol DA (2012) Female-biased offspring sex ratios in birds at a mercury-contaminated river. J Avian Biol 43: 244-251.

92. Carpenter EJ, Smith KL (1972) Plastics on the Sargasso sea surface. Science 175: 1240-1241.

93. Minchin D (1996) Tar pellets and plastics as attachment surfaces for Lepadid cirripedes in the North Atlantic Ocean. Marine Pollution Bulletin 32: 855-859.

94. Carpenter EJ, Anderson SJ, Harvey GR, Miklas HP, Peck BB (1972) Polystyrene spherules in coastal waters. Science 178: 749-750.

95. Winston JE (1982) Drift plastic-an expanding niche for a marine invertebrate. Marine Pollution Bulletin 13: 348-351.

96. Zettler ER, Mincer TJ, Amaral-Zettler LA (2013) Life in the “Plastisphere”: Microbial Communities on Plastic Marine Debris. Environ Sci Technol 47: 7137-7146.

97. Harshvardhan K, Jha B (2013) Biodegradation of low-density polyethylene by marine bacteria from pelagic waters, Arabian Sea, India. Marine Pollution Bulletin 77: 100-106.

98. Gregory MR (1991) The hazards of persistent marine pollution: drift plastics and conservation islands. Journal of the Royal Society of New Zealand 21: 83-100.

99. Gregory MR (1999) Plastics and South Pacific Island shores: environmental implications. Ocean and Coastal Management 42: 603-615.

100. Gregory MR (2009) Environmental implications of plastic debris in marine settings-entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos Trans R Soc Lond B Biol Sci 364: 2013-2025.

101. Balance A, Ryan PG, Turpie JK (2000) How much is a clean beach worth? The impact of litter on beach users in the Cape Peninsula, South Africa. S Afr J Sci 96: 210-213.

102. Choy CA, Drazen JC (2013) Plastic for dinner? Observations of frequent debris ingestion by pelagic predatory fishes from the central North Pacific. Mar Ecol Prog Ser 485: 155-163.

103. Van Cauwenberghe L, Janssen CR (2014) ‘Microplastics in bivalves cultured for human consumption’. Environ Pollut 193: 65-70.

104. Galloway T, Cipelli R, Guralnick J, Ferrucci L, Bandinelli S, et al. (2010) Daily bisphenol A excretion and associations with sex hormone concentrations: results from the In CHIANTI adult population study. Environ Health Perspect 118: 1603-1608.

105. Lang IA, Galloway TS, Scarlett A, Henley WE, Depledge M, et al. (2008) Association of urinary Bisphenol A concentration with medical disorders and laboratory abnormalities in adults 300: 1303-1310.

106. Donohue MJ (2003) How multiagency partnerships can successfully address large-scale pollution problems: a Hawaii case study. Mar Pollut Bull 46: 700-702.

107. Lentz SA (1987) Plastics in the marine environment: legal approaches for international action. Marine Pollution Bulletin 18: 361-365.

108. Ninaber E (1997) MARPOL Annex V, commercial ships, and port reception facilites: makingit work. In: Coe JM, Rogers DB (eds.), Marine Debris-Sources, Impacts and Solutions. Springer- Verlag, New York 239-243.

109. CMC-Center for Marine Conservation (2002) MARPOL/MPPRCA.

110. Watkins E, Ten Brink P, Withana S, Mutafoglu K, Schweitzer JP, et al. (2015) Marine litter: socio-economic study. Scoping report. London, Brussels.

111. Ocean Conservancy (2014) Turning the tide on trash. International Coastal Cleanup 28.

112. Wolf N, Feldman E (1991) Plastics-America’s packaging dilemma. Environmental Action Coalition. Island Press, Washington DC.

113. Gorman M (1993) Environmental Hazards-Marine Pollution. ABCCLIO Inc, Santa Barbara.

114. Barlow CY, Morgan DC (2013) Polymer film packaging for food: an environmental assessment. Resour Conserv Recycling 78: 74-80.

115. Hamann M, Godfrey MH, Seminoff JA, Arthur K (2010) Global research priorities for sea turtles: informing management and conservation in the 21st century. Endang Species Res 11: 245-269.

116. Sutherland WJ, Clout M, Côté IM, Daszak P, Depledge MH, et al. (2010) A horizon scan of global conservation issues for 2010. Trends in Ecology & Evolution 25: 1-7.

117. Laurance WF, Dell B, Turton SM, Lawes MJ (2011) The 10 Australian ecosystems most vulnerable to tipping points. Biol Conserv 144: 1472-1480.

118. Lewison R, Oro D, Godley BJ, Underhill L (2012) Research priorities for seabirds: improving conservation and management in the 21st century. Endang Species Res 17: 93-121.

119. Stern PC (2000) New environmental theories: toward a coherent theory of environmentally significant behavior. J Soc Issues 56: 407-424.

120. Brulle RJ (2010) From environmental campaigns to advancing the public dialog: environmental communication for civic engagement. Environ Commun 4: 82-98.

121. Ham S (2013) Interpretation, making a difference on purpose. Fulcrum Publishing, Golden, CO.

122. Cefas (2008) Literature review on particle assimilation by molluscs and crustaceans. Cefas Environ Rep RL 10: 17.

123. Colton JB, Knapp FD, Burns BR (1974) Plastic particles in surface waters of the Northwestern Atlantic. Science 185: 491-497.

124. Day RH, Shaw DG (1987) Patterns in the abundance of pelagic plastic and tar in the North Pacific Ocean, 1976-1985. Mar Pollut Bull 18: 311-316.

125. Eriksson C, Burton H, Fitch S, Schulz M, Van Den Hoff J (2013) Daily accumulation rates of marine debris on sub- Antarctic island beaches. Mar Pollut Bull 66: 199-208.

126. Fossi MC, Panti C, Guerranti C, Coppola D, Giannetti M, et al. (2012) Are baleen whales exposed to the threat of microplastics? A case study of the Mediterranean fin whale (Balaenoptera physalus). Marine Pollution Bulletin 64: 2374-2379.

127. Frias JPGL, Sobral P, Ferreira AM (2010) ‘Organic pollutants in microplastics from two beaches of thePortuguese coast’. Marine Pollution Bulletin 60: 1988-1992.

128. Karapanagioti HK, Endo S, Ogata Y, Takada H (2011) Diffuse pollution by persistent organic pollutants as measured in plastic pellets sampled from various beaches in Greece. Mar Pollut Bull 62: 312-317.

129. Lattin GL, Moore CJ, Zellers AF, Moore SL, Weisberg SB (2004) A comparison of neustonic plastic and zooplankton at different depths near the southern California shore. Mar Pollut Bull 49: 291-294.

130. Lusher AL, McHugh M, Thompson RC (2013) ‘Occurrence of microplastics in the gastrointestinal tract of pelagicand demersal fish from the English Channel’. Marine Pollution Bulletin 67: 94-99.

131. Moore CJ, Moore SL, Leecaster MK, Weisberg SB (2001) ‘A Comparison of Plastic and Plankton in the North Pacific Central Gyre’. Marine Pollution Bulletin 42: 1297-1300.

132. Ng KL, Obbard JP (2006) Prevalence of microplastics in Singapore’s coastal marine environment. Mar Pollut Bull 52: 761-767.

133. Noren F, Naustvoll LJ (2011) Survey of microplastic anthropogenic particles in Skagerrak. Flodevigen, Norway: Institute of Marine Research 21.

134. Ocean Conservacy (2010) International Coastal Cleanup (ICC), Trash travels: From our hands to the sea, around the globe, and through time (ISBN: 978D-615-34820-9), Washington, DC.

135. Pruter AT (1987) Sources, quantities and distribution of persistent plastics in the marine environment. Marine Pollution Bulletin 18: 305-310.

136. Rochman CM, Hoh E, Kurobe T, Teh SJ (2013) Ingested plastic transfers contaminants to fish and induces hepatic stress. Scientific Reports.

137. Song YK, Hong SH, Jang M, Kang JH, Kwon OY, et al. (2014) 'Large Accumulation of Micro-sized Synthetic Polymer Particles in the Sea Surface Microlayer'. Environ Sci Technol 48: 9014-9021.

138. Vianello A, Boldrin A, Guerriero P, Moschino V, Rella R, et al. (2013) 'Microplastic particles in sediments of Lagoon of Venice, Italy: First observations on occurrence, spatial patterns and identification'. Estuarine, Coastal and Shelf Science 130: 54-61.

139. Wong CS, Green DR, Cretney WJ (1974) 'Quantitative tar and plastic waste distributions in Pacific Ocean'. Nature 247: 30-32.

140. Zlatev M, Pahl S, White M (2010) 'Perceived risk and benefit for self and others as predictors of smokers' attitudes towards smoking restrictions'. Psychol Health 25: 167-182.

141. Plastics-Europe (2008) The compelling facts about plastics 2007: An analysis of plastics production, demand and recovery in Europe 24.

142. Arthur C, Baker J, Bamford H (2009) In: Proceedings of the International Research Workshop on the Occurence, Effects and Fate of Microplastic Marine Debris. NOAA Technical, Memorandum NOS-OR&R-30.

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