Plastic Waste in the Aquatic Environment: Impacts and Management

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Abstract:

The majority of consumer products used today is composed of some form of plastic. Worldwide, almost 280 million tons of plastic materials are produced annually, much of which end up in landfill or the oceans. Plastics are produced by the conversion of natural products or by synthesis from primary chemicals, generally from oil, natural gas or coal. In contemporary society, plastic has attained a pivotal status, with extensive commercial, industrial, medicinal and municipal applications. It affects at least 267 species worldwide, including 86% of all sea turtle species, 44% of all seabird species, and 43% of all marine mammal species. Marine animals are harmed mostly through ingestion, entanglement and subsequently strangulation. Ingested plastics debris has been found to reduce stomach capacity, hinder growth, cause internal injuries and create intestinal blockage. Plastics entanglement with nets or other materials can result in strangulation, reduction of feeding efficiency, and even drowning. Plastics pollution facilitates the transport of species to other regions, alien species hitchhike on floating debris and invade new ecosystem thereby causing a shift in species composition or even extinction of other species. Legislation, prohibiting the disposal of plastics in the sea, introducing of biodegradable plastics, recycling of plastics and public awareness campaigns to discourage littering are various ways in which this problem can be minimized. Other remedial measures include enforcing environmental laws, development of indigenous and homegrown knowledge for plastic waste management and development and implementation of quality standards for all plastic recycled products.

Keywords:

Plastics, Plastic Waste, Plastic Pollution, Aquatic Ecosystem, Marine, Impacts, Ingestion

1. Introduction

Plastics are synthetic polymers, and though they only existed for just over a century. It is a material consisting of any of wide range of synthetic or semi-synthetic organic compounds that are malleable and can be moulded into solid objects [1]. Plastics are produced by the conversion of natural products or by synthesis from primary chemicals, generally from oil, natural gas or coal [2]. Plastics are typically organic polymers of high molecular mass, but they often contain other substances. Most plastics are made from synthetic resins (polymers) through the industrial process of polymerization [1].

In contemporary society, plastic has attained a pivotal status, with extensive commercial, industrial, medicinal and municipal applications [3]. It ranks among the most widely used materials in the world [4]. In the last 60 years, plastic has become a useful and versatile material with a wide range of applications [5, 6], see Table 1. Over 300 million tons of new plastics are used every year. Half of these are used just once and usually for less than 12 minutes. Eight (8) million tons of plastic waste ends up in the ocean every year. So much is getting into the ocean that in some places these plastic particles out number plankton by a ratio of 26:1 [7]. A UNEP report [8] grossly underestimated the amount of plastic debris entering the environment at 8 million pieces per day. However, it should be noted that none of these estimates are licensed to any particular source and should be treated with caution. The world's oceans are diverse and immense; hence, to get a handle on the estimated average level of plastic waste is a very difficult task. About 49% of all produced plastics are buoyant, which gives them the ability to float, and thereby travel on ocean currents to anyplace in the world [9]. Figure 1 show how plastics are littered on the aquatic environment. Annual plastic production has increased dramatically from 1.5 million tons in the 1950s to approximately 280 million tons in 2011 [5]. Annual plastic production is estimated to hit 400 million tons by the year 2020 [10], this is depicted in Figure 2. The most common plastics are polyethylene (PE), polyethylene terephthalate (PET) and polypropylene (PP) [10].

According to the Plastic Ocean Foundation [7], the typical characteristics that render plastics so useful relate primarily to the fact that they are both flexible and durable. These characteristics become handy when plastics are used in everyday life, but when they are discarded into the environment they become a nuisance. Due to their nearly indestructible morphology and the toxins they contain, plastics can seriously affect ecosystem [11]. The biggest mass of plastics debris occurs in the oceans major gyres [12]. Therein, the rotation of vortex centers, where it accumulates currently, the plastics debris patch in the North Pacific Ocean covers an area as large as France and Spain together [12]. This debris affects all ocean life, and because we are at the top of the food chain, it affects humans too [4]. It has now been several decades since the use of plastics exploded, and there is evidence that current approach to production, use, transport, and disposal of plastic materials are caused, and are still causing serious effects on wildlife, and are not sustainable [4].

The objective of this review is to identify the sources and fate of plastic wastes on the aquatic ecosystem, to examine its impact on the aquatic biota and suggest ways to ameliorate this problem.

2. Plastic Waste in the Aquatic Ecosystem

Plastic now accounts for 10% of all waste generated, with global use exceeding 260 million tons per annum [14]. Plastics waste has accumulated in the environment at an uncontrollable rate where it is subjected to wind and river-driven transport ultimately reaching the coast. Due to its light weight, durable nature, plastics has become a prevalent, widespread element of marine litter [15, 2]. The difficulty in eliminating plastics waste is due to the fact that it does not biodegrade in nature but only photo degrades into smaller pieces.

Table 1. *Types of plastics and common use.*

Polymer type	Examples
Polyethylene Terephthalate	Fizzy drink and water bottles; Salad trays
High Density Polyethylene	Milk bottles, bleach, cleaners and most shampoo bottles
Polyvinyl Chloride	Pipes, fittings, window and door frames (rigid PVC); thermal insulation (PVC foam) and automotive parts
Low Density Polyethylene	Carrier bags, bin liners and packaging films
Polypropylene	Margarine tubs, microwaveable meal trays, also produced as fibres and filaments for carpets, wall coverings and vehicle upholstery
Polystyrene	Yoghurt pots, foam hamburger boxes and egg cartons, plastic cutlery, protective packaging for electronic goods and toys. Insulating material in the building and construction industry.
Unallocated References	Polycarbonate which is often used in glazing for the aircraft industry

Source: Adapted and modified from [6]

Figure 1. *Examples plastic litter in the aquatic environment: From left to right; plastic debris on the ocean seabed, surface water and beach. (Source: [13])*

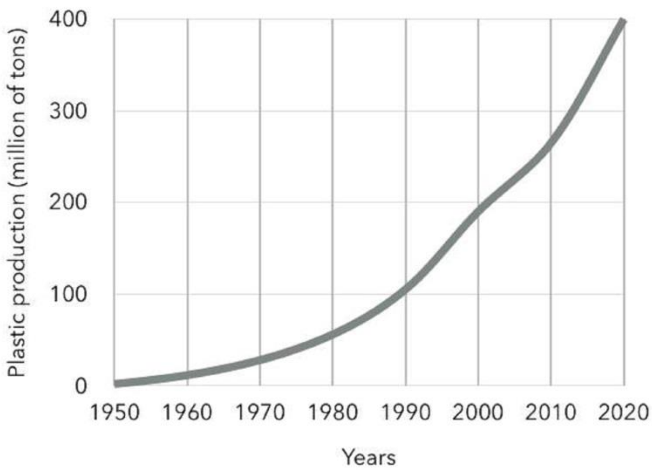

Figure 2. *Evolution of world plastic production, in million tons, from 1950 to 2020. (Source: [10])*

Because of frequent inappropriate waste management practices, or irresponsible human behavior, large masses of plastic items have been released into the environment and have consequently entered the world's oceans. This process continues, and in some places is even increasing [4]. Even if plastics are found deep in land they eventually find their way to the sea or ocean through rivers and streams [16]. The release of plastics into the environment is a result of inappropriate waste management, improper human behavior, or incidental pollution [14]. Sources of plastic waste into the aquatic ecosystem include municipal plastic waste (sachet water film bags, etc.), commercial plastic waste (packaging materials, etc.), industrial plastic waste (polyethylene film wrapping, spare parts for cars, PVC pipes and fittings, etc.), and plastic waste from ships [17, 18].

Most polymeric materials that enter the environment are subjected to degradation that is caused by a combination of factors, including thermal oxidation, photo-oxidative degradation, biodegradation and hydrolysis [19], see Table 2. Figure 3 shows the pathways and modes of movement for plastic in the marine environment. The common plastics found in the marine environments however, do not biodegrade and primarily breakdown through photo-oxidative degradation. Furthermore, unlike plastics exposed on land, exposed plastics floating on the ocean's surface do not suffer from heat build-up due to absorption of infra-red radiation, and the reform barely undergo thermal oxidation [20].

The degradation of negatively buoyant plastics depends on very slow thermal oxidation, or hydrolyses, as a result of most wavelengths being readily absorbed by water. Hence, plastics residing in marine environments degrade at a significantly slower rate than they do on land. Polymer degradation can be categorized as any physical or chemical changes resulting from environmental factors, including light, heat, moisture, chemical conditions and biological activity [19]. It is not clear just how long plastic items remain in their original form. However, some plastic items appear to be broken up into smaller and smaller fragments over time [21]. At sea, this process is thought to occur due to wave action, oxidation and ultraviolet light. On the shore, it may break up into smaller pieces due to grinding from rocks and sand [22]. The resulting plastic fragments may be mistaken for prey and ingested by marine organisms. Plastic debris in the oceans may eventually be broken up so much that it becomes microscopic in size like grains of sand, hence called micro plastics. These tiny fragments (about 20μm in diameter) have been identified in marine sediments and in ocean waters [23].

Various studies have demonstrated occurrence of marine debris worldwide with plastic making up the major proportion of marine debris. Reports from some of these studies are summarized in Table 3. Though the methods were not assessed to ensure that the results were comparable, Table 3 clearly indicates the predominance of plastics amongst the marine litter, and its proportion consistently varies between 60% and 80% of the total marine debris [24].

Table 2. *Possible degradation routes of synthetic polymers.*

Requirements	**Photo-degradation**	**Thermal/thermo-oxidative degradation**	**Biodegradation**
Active ingredients	UV-light/high energy radiation	Heat and/or oxygen	Microbial Agents
Heat requirement	None	Above ambient temperature	None
Degradation rate	Slow initiation, fast propagation	Fast	Moderate

(Source: [19])

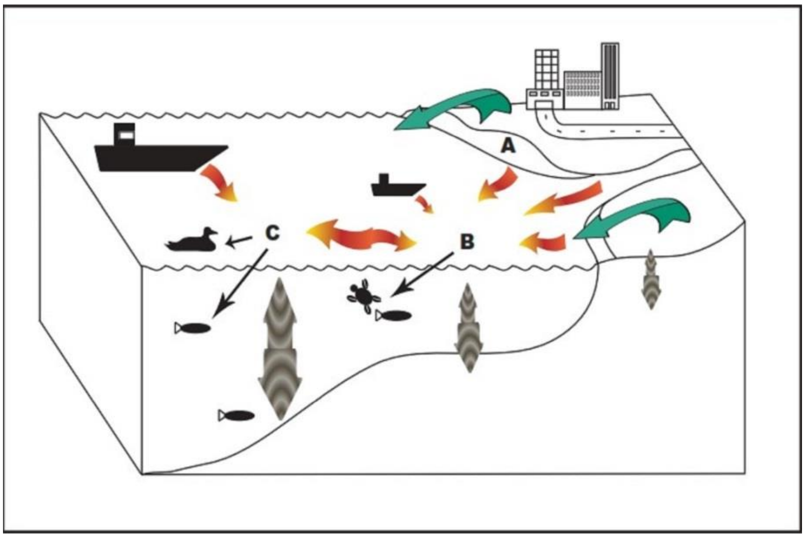

Figure 3. *Schematic diagram indicating the pathways and modes of movement for plastic in the marine environment. (a) beaches (b) coastal waters and sediments (c) open ocean.*

Green arrows indicate wind-blown debris, grey arrows display vertical movement through the water column including sea floor deposition and burial, black arrows point to ingestion and entanglement by marine organisms, and red arrows indicate water borne debris (Source: [25]).

Table 3. *Proportion of plastics among marine debris worldwide (per no. of items).*

Locality	**Litter type**	**Percentage of debris items represented by plastics**	**Source**
1992 International Coastal Clean-ups	Shoreline	59	[26]
St. Lucia, Caribbean	Beach	51	[27]
Dominica, Caribbean	Beach	36	[27]
Curacao, Caribbean	Beach	40/64	[28]
Bay of Biscay, NE Atlantic	Seabed	92	[29]
NW Mediterranean	Seabed	77	[30]
French Mediterranean Coast	Deep sea floor	>70	[31]
European coasts	Sea floor	>70	[32]
Caribbean coast of Panama	Shoreline	82	[33]
Georgia, USA	Beach	57	[34]
5 Mediterranean beaches	Beach	60–80	[35]
50 South African beaches	Beach	>90	[24]
88 sites in Tasmania	Beach	65	[24]
Argentina	Beach	37–72	[24]
9 Sub-Antarctic Islands	Beach	51–88	[24]
South Australia	Beach	62	[24]
Kodiak Is, Alaska	Seabed	47–56	[36]
Tokyo Bay, Japan	Seabed	80–85	[37]
North Pacific Ocean	Surface waters	86	[38]
Mexico	Beach	60	[39]
Transkei, South Africa	Beach	83	[40]
National Parks in USA	Beach	88	[41]
Mediterranean Sea	Surface waters	60–70	[42]
Cape Cod, USA	Beach/harbour	90	[43]
4 North Atlantic harbours, USA	Harbour	73–92	[43]

Is. Beach State Park, New Jersey, USA	Beach	73	[44]
Halifax Harbour, Canada	Beach	54	[45]
Price Edward Is., Southern Ocean	Beach	88	[46]
Gough Is., Southern Ocean	Beach	84	[46]
Heard Is., Southern Ocean	Beach	51	[47]
Macquire Is., Southern Ocean	Beach	71	[47]
New Zealand	Beach	75	[48]
Two gulfs in W. Greece	Seabed	79–83	[49]
South German Bight	Beach	75	[50]
Bird Is., South Georgia, Southern Ocean	Beach	88	[51]
Fog Bay, N. Australia	Beach	32	[52]
South Wales, UK	Beach	63	[53]

* Is. - Island. (Source: [1])

3. Impacts of Plastic Waste on the Biota of the Aquatic Ecosystem

The properties that make plastics such desirable materials for modern society can make them lethal for wildlife, when introduced into the environment [4]. Numerous species are affected by plastic pollution, primarily because organisms become entangled in plastic nets, or plastic objects are ingested when organisms mistake plastic debris for food [54]. Another problem of plastics pollution is that it facilitates the transport of species to other regions; alien species hitchhike on floating debris and invade new ecosystem thereby causing a shift in species composition or even extinction of other species [55]. Plastics also transfer contaminants to the environment or to organisms when ingested [56]. A technical report considering the impacts of marine debris on biodiversity revealed that over 80% of reported incidents between organisms and marine debris was associated with plastic whilst 11% of all reported encounters are with micro plastics [57]. Although plastic is often buoyant, it can sink to the bottom of the sea, pulled down by certain ‘bottom-hugging’ currents, oceanic fronts or rapid and heavy fouling. Sediment may also help keep plastic on the seafloor [5]. It is likely that once on the seafloor; plastic will change the workings of the ecosystem. Goldberg [58] has suggested the plastic sheets could act lake a blanket, inhibiting gas exchange and leading to anoxia or hypoxia (low oxygen levels). Plastic waste could also create artificial hand grounds [59] and cause problems, especially for burying creatures.

There is still relatively little information on the impact of plastics pollution on the oceans ecosystems [60, 61]. There is however an increasing knowledge about their deleterious impacts on marine biota [58]. The threats to marine life are primarily mechanical due to ingestion of plastic debris and entanglement in packaging bands synthetic ropes and lines, or drift nets [38, 54, 60], see Figures 4 and 5. Since the use of plastics continues to increase, so does the amount of plastics polluting the marine environment. In addition to impact on marine and life, plastic debris can also damage marine industrial (entangling propellers and blocking cooling systems). It has been estimated that marine debris damage to the marine industry in the Asia-pacific region coasts $1.26 billion annually [62].

3.1. Impact on Faunal Communities

The magnitude of plastic pollution carried to sea has significantly multiplied over the past several decades. Oftentimes, wildlife is injured due to entanglement or ingestion of the plastics found in the environment. It was shown that at least 267 marine species worldwide suffer from entanglement and ingestion of plastic debris [54], see Table 4. When such contact occurs, organisms are seriously affected in a way that quite results in death. It is very difficult to estimate what the total effect of plastic debris in the ocean is or to predict the consequences for organisms that ingest or otherwise contact that debris because it cannot be directly observed. By contrast, entanglement can be observed, and is the most visible effect of plastic debris on organisms in the marine environment. Laist [54] studied and composed a comprehensive list of species that suffered from entanglement caused by marine debris entanglement (see Table 4). Nevertheless, the exact extent of entanglement faced by marine organisms is difficult to qualify, because entanglement generally occurs in areas remote from human activity.

Entanglement can cause death by drowning, suffocation, strangulation or starvation [21]. Very often, birds, small whale species and seals drown in ghost nets lose. They may also lose their ability to catch food, or cannot avoid predators because of their entanglement [1]. Plastic debris that pollutes the marine environment is often ingested by marine birds, mammals, turtles, and fish [54]. The ingestion of plastics primarily occurs when it is mistaken for food, but can also occur from incidental intake. The ingested materials often consist of micro and meso-debris sized fragments which sometimes are able to pass through the gut without hurting the organisms. In most cases, however, fragments become trapped inside the stomach, throat, or digestive tract and cause damage (e.g. sgar objects) or a false sense of fullness, which will result in starvation. Table 4 shows the list of affected species by plastic waste. The list of affected species indicates that marine debris is affecting a significant number of species [54], see Table 4. It affects at least 267 species worldwide, including 86% of all sea turtle species, 44% of all seabird species, and 43% of all marine mammal species [54]. The problem may be undiscovered over vast ocean areas, as they either sink or are eaten by predators [63]. Globally at least 23% of marine mammal species, 36% of seabird species and 86% of sea turtle species are known to be affected by plastic debris [64].

a. Coastal and Marine Birds

Many birds in the marine environment dive for food, and thereby come into contact with plastic debris. The greatest causes of entanglement by seabirds are fishing lines and six-pack rings. Both materials are often transparent and difficult to see. If seen, they can be mistaken for Jellyfish and other food [21]. The gannet is one marine bird species that is endangered by plastic debris. As a “plunge-diver”, the gannet dives from great heights into the ocean and can thereby be caught by ghost nets or other debris. A study at the Island of Helgoland in Germany, which hosts a large gannet colony, showed that between 1976 and 1985, 29% of dead gannets found had become entangled in net fragments [65]. High proportions of coastal and marine bird species (36% of the 312 species worldwide) ingest plastic fragments [54], see Figure 4. Allsopp et al. [21] reported that, 111 out of 312 species of seabirds are known to have ingested debris and it can affect a large percentage of a population (up to 80%). Moreover, plastic debris is also known to be passed to the chicks in regurgitated food from their parents.

One harmful effect from plastic ingestion in birds is weight loss due for example to a falsely sated appetite and failure to put on adequate fat stores for migration and reproduction [21]. Although plastics are mainly ingested by birds because they are mistaken for food, they may also already be present in the gut of their prey, or may be passed from adult to chick by regurgitation feeding. Some species feed selectively on plastics fragments that have a specific shape or color [66]. Robards et al. [67] examined the gut content of thousands of birds in two separate studies, and found that the ingestion of plastics by seabirds had significantly increased during the 10-15 years' interval between studies. A study done in the North pacific by Blight and Burger [68] found plastics particles in the stomachs of 8 of the 11 seabird species caught as by-catch. Harmful effects from the ingestion of plastics include blockage of gastric enzyme secretion, diminished feeding stimulus, lowered steroid hormone levels, delayed ovulation and reproductive failure [69]. The food uptake, cause internal injury and death following blockage of intestinal tract [70, 71, 72, 73], the extent of the harm, however, will vary among species. Laist [38] and Fry et al. [74] observed that adults that manage to regurgitate plastic particles could pass them onto the chicks during feedings.

The harm from ingestion of plastic is nevertheless not restricted to seabirds. For Procellariformes such as the Albatrosses (Figure 2), Shearwaters, or Petrels, the appearance of eroded plastic pieces are similar to many types of food they consume [68]. Small plastics such as bottle caps are often mistaken by seabirds (Procellariformes) for food. In several studies it was found that diving birds that fed on fish in the water column had less plastic in their stomachs compared to those that were surface eaters [68, 75]. This could be because birds that maintain a diet of zooplankton may not be able to distinguish between plastics and their primary source of food due to the colour or shape of the plastic pieces [76]. Since most adult birds regurgitate what has been ingested as a way to feed their chicks, they pass the bolus containing the plastic in the first young. Birds such as the Albatross and Shearwater had more plastic in the first region of their stomachs and gizzards, indicating that when these plastic were regurgitated, they would be passed to their young during feeding [66]. Juvenile albatross and shearwaters were found to ingest more plastics than adults [76, 77]. Similar to other marine life, swallowed plastics can obstruct and damage a bird's digestive system, reducing its foraging capabilities. Ryan [72] concluded that ingested plastics could reduce the fitness, growth rate, and food consumption of seabirds. Based on the results form a study using domestic chickens (*Gallus domesticus*), the amount of plastic ingested by different species of birds may be an indicator of the accumulation of plastics in an area.

b. Fish

The incidence of accidental entangle of fish species is difficult to estimate, because certain fish are "intended" to become entangled in nets. Therefore, research emphasizes by-catch of endangered species. For example, between 1978 and 2000; 28,687 Shark were caught in nets that protected people at popular swimming beaches in Kwazulu, South Africa [4]. Microplastics resemble phytoplankters which are eaten by fish and cetaceans [78], see Figure 4. Ingested plastic debris has been found to reduce stomach capacity, hinder growth, cause internal injuries, and create intestinal blockage [79].

Ghost fishing can lead to economic losses for fisheries [21]. For example, an experimental study on ghost fishing of monkfish from lost nets in the Cantabrian Sea, northern Spain, estimated that 18.1 tons of monkfish are captured annually by abandoned nets. This represented 1.46% of the commercial landings of monkfish in the Cantabrian Sea [80]. A study on ghost fishing by lost pots off the coast of Wales, UK, noted that potential losses to the brown crab fishery caused by ghost fishing could be large [81]. In the USA it was estimated that $250 million of marketable lobster is lost annually to ghost fishing [82].

c. Mammals

Many seal species are curious and playful, and especially young seals are attracted to plastic debris and swim with it or poke their head through loops. Plastic rings, loops, or lines easily glide onto the seal's neck, but are difficult to remove due to the backward direction of the seal's hair (see Figure 5). As the seal grows, the plastic collar tightens and strangles the animal or it's arterially in the North Sea where their vision is limited [4]. After entanglement in these nets the animals are not able to reach the water surface and drown. An estimated 58% of seal and sea lion species are known to have been affected by entanglement including the Hawaiian monk seal, Australian sea lions, New Zealand fur seals and species in the Southern Ocean [21].

Whales also become entangled in marine debris. However, although some whale species are incapable of freeing themselves and consequently drown, the larger size whales often drag fishing gear away with them. This latter type of entanglement can cause strangulation and can affect the feeding ability of the whale in ways that causes starvation. At least 26 species of cetaceans have been documented to ingest plastic debris [83]. A young male pygmy sperm whale (*Kogia breviceps*) stranded alive in Texas died in a holding tank 11 days later. Stomach compartments were completely occluded by plastic debris including garbage can, liner, a bread wrapper, a corn chip bag and two other pieces of plastic sheeting [83]. Entanglement is a particular problem for marine mammals, such as fur seals, which are both curious for catch food or to avoid predators impaired, they may incur wounds from abrasive or cutting action of attached debris [38, 84]. According to Feldkamp et al. [85] entanglement can greatly reduce fitness, as it leads to a significant increase in energetic costs of travel-for the northern for seals (*Callorhinus ursinus*). For instance, they started that net fragment over 200g could result in 4-fold increase in the demand of food consumption to maintain body condition [85]. Most cetaceans live far from the shoreline which limits the amount of research on the ingestion of marine debris. If plastic causes unnatural death, cetacean will most likely sink to the bottom of the ocean [83]. Occasionally, cetacean will wash ashore allowing for post-mortem examinations. Due to cetacean echo-location capabilities, mistaken consumption of plastic is not probable [86].

Ingestion is most likely because the debris was mixed in with the desired food. Two sperm whales (*Physeter macrocephalus*) were found off the coast of northern California in 2008 with a large amount of fishing gear in their gastrointestinal tracts [87]. One of the sperm whales had a rupture in their compartment of the stomach caused by nylon netting. On the other hand, netting, fishing line, and plastic bags completely blocking the stomach from the intestines [87]. On the coast of Nova Scotia, Canada, a juvenile porpoise (Phocoenidae) was found dead with a balled up piece of black plastic in the oesophagus entangled with three spine stickleback fish [83]. In Brazil, the stomach analysis of Blaiville's beaked whale (*Mesoplodon densirostris*) showed the presence of a large bundle of blue plastic thread occupying a substantial part of the stomach chamber [86]. Ayalon [88] argued that within the last decade, at least seven ending mass amounts of tangled nylon rope and other debris including a crayfish pot and a buoy with macker poly have been found in the stomach of whales. Currently there have not been enough trends found in collected data that prove ingested plastics are the primary cause of death that proved ingested plastic are the primary cause of death contributing to the decline of cetaceans [89, 90, 91]. Plastic entanglement with nets or other materials can results can result in strangulation, reduction of feeding efficiency, and in some cases drowning [92]. Due to natural curiosity, pinnipeds often become entangled in marine debris of life [92].

d. Reptiles

Polythene bags drifting in ocean currents look much like the prey items targeted by turtles [93, 94, 95], see Figure 4. There is evidence that their survival is being hindered by plastics debris [96] with young sea turtles being particularly vulnerable [97]. Balazs [98] listed 79 cases of turtles whose guts were full of various sorts of plastic debris and O'Hara et al. [99] cited a turtle found in New York that has swallowed 540m of fishing line. Entanglement in plastic debris, especially in discarded fishing gear, is a very serious threat to marine reptiles. It also affects the survival of sea turtles as there are endangered [97].

e. Invertebrates

Plastic effects on invertebrates are mainly attributed to microplastics. Various studies have been well documented including [3, 100, 101, 102, 103]. Some of the effects of microplastics on aquatic invertebrates include blockages throughout the digestive system or abrasions from sharp objects resulting in injuries, blockage of enzyme production; diminished feeding stimulus; nutrient dilution; reduced growth rates; lowered steroid hormone levels; delayed ovulation and reproductive failure; and absorption of toxins [3]. There is potential for micro plastics to clog and block the feeding appendages of marine invertebrates or even to become embedded in tissues [1]. Table 5 presents a comprehensive list of evidence of impacts of plastic debris on marine organisms by various studies.

Figure 4. *Marine organisms ingesting plastic debris: From left to right; recovering plastic debris from carcass of an Albatross, plastic debris retrieved from a filleted fish and a turtle eating plastics (polyethylene sachet film). (Source: [13])*

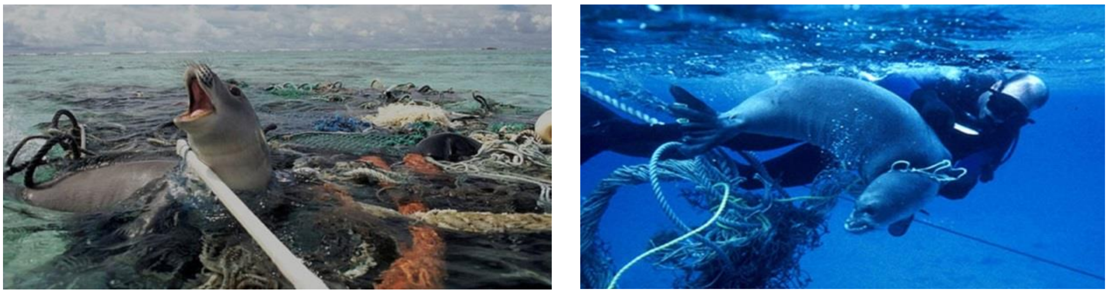

Figure 5. *Entanglement effect of plastic debris on seals: From left to right; seal trapped by a discarded fishing net and seal entangled by ghost fishing lines. (Source: [13]).*

Table 4. Number and percentage of marine species worldwide with documented entanglement and ingestion records

Species Group	Total no. of spp. worldwide	No and % of spp. with entanglement records	No and % of spp. with ingestion records
Sea Turtles	7	6 (86%)	6 (86%)
Seabirds	312	51(16%)	111(36%)
Penguins (Sphenisciformes)	16	6 (38%)	1(6%)
Grebes (Podicipediformes)	19	2 (10%)	0
Albatrosses, Petrels, and Shearwaters (Procellariiformes)	99	10 (10%)	62 (63%)
Pelicans, Boobies Gannets, Cormorants, Frigate birds and Tropicbirds (Pelicaniformes)	51	11 (22%)	8 (16%)
Shorebirds, Skuas, Gulls, Terns, Auks (Charadriiformes)	122	22 (18%)	40 (33%)
Other birds	-	5	0
Marine Mammals	115	32 (28%)	26 (23%)
Baleen Whales (Mysticeti)	10	6 (60%)	2 (20%)
Toothed Whales (Odontoceti)	65	5 (8%)	21 (32%)
Fur Seals and Sea Lions (Otariidae)	14	11 (79%)	1 (7%)
True Seals (Phocidae)	19	8 (42%)	1 (5%)
Manatees and Dugongs (Sirenia)	4	1 (25%)	1 (25%)
Sea Otter (Mustellidae)	1	1 (100%)	0
Fish	-	34	33
Crustaceans	-	8	0
Squid	-	0	1
Species Total		136	137

(Source: [54])

Table 5. Peer-reviewed studies demonstrating evidence of impacts of plastic marine debris

Study	Animal	Encounter type	Predominant debris type	Impact response
[92]	Grey seals	Entanglement	MF line, net, rope	Constriction
[104]	Manatees	Entanglement	MF line, bags, other debris	Death
[105]	Elephant seals	Entanglement	MF line, fishing jigs	Dermal wound
[106]	Fur seals	Entanglement	Packing bands, fishing gear, other debris	Dermal wound
[107]	Seabirds, pinnipeds	Entanglement	Fishing gear	External wound
[108]	Fur seals	Entanglement	Trawl netting, packing bands	Death
[108]	Fur seals	Entanglement	Trawl netting, packing bands	Reduced population size
[109]	Invertebrates,	Entangle	Derelict gillnets	Death

	fish, seabirds, marine mammals	ment		
[110]	Seabirds, marine mammals	Entanglement	Plastic, fishing line	Death
[111]	Gorgonians	Entanglement	Fishing line	Damage/breakage
[112]	Sea turtles	Entanglement	Fishing gear	Death
[113]	Whales	Entanglement	Plastic line	Dermal wound
[114]	Whales	Entanglement	Plastic line	Dermal wound
[104]	Manatees	Ingestion	MF line, bags, other debris	Death
[115]	Sea turtles	Ingestion	MF line, fish hooks, other debris	Intestinal blockage, death
[116]	Penguins	Ingestion	Plastic, fishing gear, other debris	Perforated gut, death
[117]	Lugworms(laboratory)	Ingestion	Microplastics	Biochemical/cellular, death
[95]	Sea turtles	Ingestion	Plastic bags, ropes	Gut obstruction, death
[118]	Seabirds	Ingestion	Plastic particles, pellets	Perforated gut
[119]	Fish(laboratory)	Ingestion	Nanoparticles	Biochemical/cellular
[120]	Seabirds	Ingestion	Plastic pellets, foam	Biochemical/cellular
[107]	Seabirds, pinnipeds	Ingestion	Fishing hooks	Internal wound
[90]	Sperm whale	Ingestion	Identifiable litter items	Gastric rupture, death
[74]	Seabirds	Ingestion	Plastic fragments, pellets, identifiable litter	Gut impaction, ulcerative lesions

Table 5. *Continued*

Study	**Animal**	**Encounter type**	**Predominant debris type**	**Impact response**
[87]	Sperm whales	Ingestion	Fishing gear, other debris	Gastric rupture, gut impaction, death
[121]	Copepods(laboratory)	Ingestion	Micro- and Nano plastics	Death
[122]	Fish(laboratory)	Ingestion	Microplastics	Biochemical/cellular
[123, 124, 125]	Fish(laboratory)	Ingestion	Microplastics	Biochemical/cellular
[72]	Birds(laboratory)	Ingestion	Microplastics	Reduced organ size
[112]	Sea turtles	Ingestion	Marine debris	Gut obstruction
[3]	Lugworms(laboratory)	Ingestion	Microplastics	Biochemical/cellular
[126]	Mussels(laboratory)	Ingestion and gill uptake	Microplastics	Biochemical/cellular
[127]	Epibenthic megafauna	Interaction(contact)	Plastic bottles, glass jars	Altered assemblage

[128]	Sessile invertebrates (coral reef)	Interaction(contact)	Lobster traps	Altered assemblage
[129]	Assemblage on sediment	Interaction(contact)	Plastic litter	Altered assemblage
[130]	Sessile invertebrates (coral reef)	Interaction(contact)	MF line, lobster trap, hook and line gear	Tissue abrasion
[131]	Sessile invertebrates (coral reef)	Interaction(contact)	Hook and line gear	Tissue abrasion
[132]	Seagrass	Interaction(contact)	Crab pots, tires, wood	Breakage, suffocation, death
[133]	Sea turtles	Interaction(obstruction)	Waste, medical waste	Reduced population size
[134]	Ghost crabs	Interaction(obstruction)	Beach litter, mostly plastic	Reduced population size
[134]	Ghost crabs	Interaction(substrate)	Beach litter, mostly plastic	Altered assemblage
[101]	Marine insects	Interaction(substrate)	Microplastics	Increased population size

This table is based on analysis by [135] for publications through the year 2013, extracting studies for plastic marine debris only. *MF, monofilament line. (Source: [136]).

3.2. Impact on Floral Communities

Impact on plant communities is minimal compared to threats to animals. Natural flotsam, of both marine and terrestrial origin (seaweeds and plants) together with jetsam of indeterminate sources, tends to accumulate along high tide strandlines, where it is commonly known as the 'the wrack' [59]. These areas are often ephemeral, dynamic and seasonal environments and also tend to accumulate significant quantities of manufacture materials, in particular also made of plastic and other non-destructible [59]. As a consequence, wrack environments are commonly unsightly and the demands of local authorities to clean up the mess are frequent and can be expensive [137, 138]. Maximum impacts on the floral communities are however observed in the form of micro plastics. Recent studies such as [3] emphasized the important role of micro plastics as they are easily ingestible by small organisms, such as plankton species, and form a pathway for contaminants to enter the food web.

3.3. Invasive Species

The presence of industrial pellets on beaches free from the influence of petrochemical facilities and pellet processing plants is an indication of long-range marine transport [139]. Like all natural or artificial floating debris, plastic can provide a mechanism for encrusting and fouling organisms to disperse over great distances [140]. Logs, pumice and other flotsam have traversed the open ocean for millennia [59], and the introduction of hard plastic debris to the marine ecosystem may provide an appealing and alternative substrate for some opportunistic colonizers [141, 59]. It is estimated that if biotic mixing occurs, global marine species diversity may decrease by up to 58% [142]. Barnes [143] estimates the propagation of fauna in the sea has doubled in the tropics, and more than tripled at high latitudes (>50o), due to the input of anthropogenic debris. The hard surfaces of plastics provide an ideal substrate for opportunistic colonizers. Pelagic plastics are most commonly colonized by bivalve mollusks; however, other encrusting organisms include bacteria, diatoms, algae and barnacles [70, 1, 141, 59, 134].

Plastic substrates may also contain multispecies habitats composed of organisms that would normally inhabit different ecological niches [140]. Drifting plastic debris may also increase the range of certain marine organisms or possibly introduce species to new environments which they had previously not been inhabited [144]. Sensitive or at-risk littoral, intertidal and shoreline ecosystems could be negatively affected by the arrival of unwanted and aggressive alien species with potentially damaging environmental consequences [140, 145, 146, 59]. The absence of biological organisms on plastic debris may be an indication that the particles were not present in the marine environment long enough for fouling to occur. Instead, these items probably have a more local, land-based origin (beachgoers, storm-water drainage), than more heavily encrusted debris [134]. Plastic waste also affects beaches.

Plastic waste could encourage the invasion of species who prefer hard surfaces and as a result, indigenous species may be displaced, particularly those who prefer sandy and muddy bottoms [5]. So-called 'wrack' environments consist of national flotsam and jetsam such as seaweed driftwood etc. that is washed up on the shore, and often contains plastic waste [5]. Beach clean-ups are way to remove plastic waste, but it is often assumed that the beach will return to its previous state once the clean-up is done [5].

3.4. Ecotoxicology

Plastics are considered to be biochemically inert because of their macro molecular structures, they neither react with, nor penetrate the cell membrane of an organism [4]. However, most plastics are not pure. Besides their polymeric structure, they consist of a variety of chemicals that all contribute to a certain property of the plastics they comprise [4]. Additives are mostly of small molecular size are often not chemically bound to a polymer and are, therefore, able to leach from the plastics. Being primarily lipophilic, they penetrate cell membranes, interact biochemically, and cause toxic effects, moreover plastics debris in the marine environment not only contains additives, but also contains chemicals (Contaminants) adsorbed from the surrounding water [4]. The hydrophobic surface of plastics has an affinity for various hydrophobic contaminants, and these are taken up from the surrounding water and accumulate on, and in the plastics debris. This mechanism receives great attention for micro debris or micro plastics, because they are easily ingested by organisms and constitute a pathway for chemical to enter an organism [103].

Plastics debris in the marine environment can contain two types of possible toxic contaminants, additives and hydrophobic chemicals that become adsorbed from the surrounding water [56]. In the marine environment, absorption of contaminants by polymers is primarily studied with meso-plastic and micro plastic debris. Absorption reduces the transport and diffusion of contaminants. Hydrophobic organic contaminants have a greater affinity for plastics like polyethylene, polypropylene, and PUC, than for natural sediments [56]. Flame retirements are also present as additives in plastics and have added to many common products. The majority of flame retardants (BFFS) BFF are widely used in plastics produces because they affect material prosperities in only a minor way, and are very effective in preventing ignition.

However, they are also present as contaminants almost everywhere in the world's environment; they exist in air, rivers, and waters up to the Arctic regions.

Ingestion of plastic fragments by seabirds and fish may be the source of bioaccumulation of heavy metals, PCBs, dichlorodiphenyltrichloroethane (DDT), and other toxins [72]. Absorption and transfer of these chemicals by filter feeding organisms and invertebrates may lead to reproductive disorders, disease, altered hormone levels, or death at higher trophic levels [72, 25, 147, 148].

4. Management and Preventive Measures

4.1. Prevention and Control

Marine plastic pollution shows that we cannot really throw anything away. Reducing, revising and recycling are the best way to stem the tide of plastics into our oceans. Moss [149] suggested the following ways in preventing and controlling plastic waste.

Hold plastic producers accountable. Many countries hold producers of materials like paints and carpet responsible, for recovering and recycling their product after it is used.

Boxes should be preferred; laundry detergent and dish soap in boxes instead of plastic bottles card board can be more easily recycled and made into more products than plastic.

Use reusable bottles and cups: Bottled water produces 1.5 million tons of plastic waste per year, and these bottles require 47 million gallons of oil to produce. By simply refilling a reusable bottle, plastics can be prevented from ending up in the ocean.

Reduced use of plastic ware: Use of silverware should be encouraged as use of plastic ware will increase risk of plastic waste.

4.2. Management Procedures

There are various ways for management of plastic waste in the aquatic ecosystem. The following and not limited to be the management procedures:

a. Public awareness and Education

Both formal and informal education is urgently needed to raise the publics' awareness of the negative impact of irresponsible waste disposal in general and plastic waste in particular. Education must also be used to forge a positive change in on attitude to plastic waste management [17]. Education is also a very powerful tool to address the issue, especially if it is discussed in schools, youngsters not only can change habits with relative ease, but also be able to take their awareness into their families and the wider community, working as catalysts for change. Since land-based sources provide major imputes of plastic debris into the oceans, if a community becomes aware of the problem and obviously willing to act upon it, it can actually make a significant difference. The power of education should not be underestimated, and it can be more effective than strict laws, such as the Suffolk county plastics law (in New York, USA) that banned some retail food packaging and was unsuccessful in reducing beach and roadside litter [150].

b. Recycling of plastics through environmentally sound manner

Recycling, in simple terms, is defined as the conversion of used materials (waste) into new products. The purpose of recycling is to:

- Prevent waste of potentially useful materials,
- Reduce the consumption of fresh raw materials,
- Reduce energy usage,
- Reduce air pollution (from incineration) and water pollution (from land filling) by reducing the need for "conventional" waste disposal, and lower greenhouse gas emissions as compared to virgin production [17].

According to a feasibility study on plastics waste by Centre for Scientific and Industrial Research (CSIR) in Ghana; GHC 1,200,000 can be generated every month, if plastics waste goes through various stages towards recycling. Recycling therefore provide opportunities for effective management of plastics waste management, as well as income generation. However, though some plastic wastes recycling plants have been established, the menace still persists. Funding and capacity have been identified as the major problems hindering recycling of waste. It is therefore proposed that:

- A plastic waste management fund should be created to support recycling and upgrading of plastic waste infrastructure to promote private-public partnerships in the development and management of plastic waste infrastructure. The fund should be resourced with voluntary contributions from industry, Government and other donors; and these contributions are tax exempt.
- Set up of differential power and water tariffs to increase the level of recycling.
- Zero- rating of recycled products to create a vibrant market for recycled products.
- Supporting the development of biodegradable bags that are more durable, reusable and recyclable
- Preferential tax treatment to the private sector for the construction of plastics waste treatment plants.
- A voluntary code of practice for retailers, consumers and manufacturers aiming at rationalizing the issuance of plastics, increasing the usage of plastic bags made from recycled material, creation of convenient and accessible recycling stations to customers, and setting up of better standards for imported packaging plastics [17].

c. Establishment of a Waste Stock Exchange (WSE)

One of the emerging systems that is increasingly assuming a pivotal role in the achievement of recycling and resource recovery is an on-line waste stock exchange. This system will serve as an on-line Waste Exchange Network available for all companies in the country, to increase business profitability by promoting waste trading and recycling [151]. This system will streamline cooperation between waste producers, re-users and business advisers making transactions quicker and easier to achieve. This web-based mechanism will serve as secondary raw materials market that solves logistical and qualitative problems for all public and private entities that could potentially use some kind of waste in their production cycles, or that implement recycling and recovery programs [151]. It is an innovative and efficient instrument, if introduced in a solid legal and economic context, as is typical of a free and competitive market will promote the reuse and recycling of industry by-products and wastes [151].

d. Conversion of Plastics Waste into Artifacts

Another option for sustainable plastic wastes management is conversion into artifacts such beads, bags, door mats and hats. This option should be promoted in basic and secondary schools [17].

e. Encourage the Use Bio-Based and Biodegradable Plastics

Another way to prevent the input of persistent plastics into the marine environment is to introduce biodegradable plastics. Biodegradable plastics are made of renewable sources, and consist of polymers that are capable of undergoing decomposition into carbon dioxide, water, methane, inorganic compounds or biomass, Biodegradation of these polymers is achieved by the use of microorganism that have the ability to catabolize these polymers into less environmentally harmful marital [152]. The residue of degraded polymers is often used as plant fertilizer and these plants can serve as a new source for manufacturing biodegradable polymers. Recently progress has been made in developing biodegradable plastics that possess characteristic similar to those of oil-based polymers [153]. Bio-based and biodegradable plastics are on the rise; numerous new products have been developed, achievable properties are much more diverse and possible applications for these materials are much more versatile than they were just a few years ago. With regard to the end of-life phase, biodegradable and compostable plastics offer additional recovery options, like composting or anaerobic digestion. Biodegradability is a special feature which is particularly attractive when economic and/or ecological benefits can be gained by leaving plastic products in the soil or bio waste stream. For example, used as bio waste bags, biodegradable plastics support a clean separation and collection of organic waste: divert from landfill towards high quality compost production. Composting is important for areas when soil erosion is a serious problem [17]. Biodegradable plastics, or bioplastics, often have inferior performance compared to traditional plastics because they eventually become permeable in water. Therefore, bioplastic materials are used as disposable items, such as packaging material. The biodegradable polymers that are used are of diverse types. Bioplastics that are based on polylactic acid (PLA) and plastarch material (PSM) are two of the most commonly used ones in current commercial practice.

f. Impose levies on Plastic Shopping Bags

One practical option to reduce the rate of generation of plastic waste is by discouraging overuse or misuse of plastic wrappers and carrier bags. The "abuse" of plastic shopping bags is a serious and visible environmental problem [17]. To address the "abuse" of plastic shopping bags at source, Government should impose an environmental levy on plastic shopping bags, with the first phase covering chain and large supermarkets, convenience stores and personal health and beauty stores. Aside from reduction at source through the environmental levy, Government should also encourage the reuse, recovery and recycling of plastic shopping bags, through source separation of waste programmer and community campaigns [17]. In some countries, whereas alternative paper wrappers/bags are free in shops, plastic wrappers/bags carry a fee that is used to subsidize the more expensive production of paper wrappers/bags. The reason is that paper waste decays, so it does not endanger the environment. However, concerns about cutting trees for paper production and its negative impact on the environment must be borne in mind. Re-use of plastic carrier bags should be vigorously encouraged and practiced by all to minimize plastic waste generation [17].

g. Increment in the Thickness of Plastic Films

There is also need to consider increasing the thickness of the plastic film used in manufacturing carrier bags from the current 9-11 micrometers to a minimum of 30 micrometers. This indeed is the situation in countries such as India. The increased thickness of plastic film is expected to reduce excessive contamination of plastic waste (that increases recycling costs), and makes discarded carrier bags difficult for the wind to blow around. It is proposed however, that any increase in thickness of plastic film must be accompanied by adoption of a technology that provides a line of weakness on water sachets and other plastic containers that need to have one end torn before their contents can be used [17].

h. Household Segregation, Re-use and Recycling

Waste should be regarded as a great economic resource. The segregation, re-use and recycling of waste at the household levels or point of generation should be encouraged. Paper, plastics, organic matter, metals and glass could all be recycled or converted to usable materials. In order to make user charges effective, there is the need to tailor such charges to the level of environmental consciousness of residents, and their ability to pay [17]. Very serious consideration must be given to how more money could be generated to improve the delivery of the service. The Government in the long-term should consider adopting and modifying the use of other economic instruments such as:

- Institution of solid waste pricing systems that will provide continuous incentives for households to reduce waste generation (e.g. pay-per-volume of waste);
- Disposal charges levied on dumping of industrial and municipal waste at landfill sites. Rate of charges should depend on type of waste and method of treatment before dumping;
- Incentive schemes such as subsidies, concessional loans and tax incentives to encourage District Assemblies and private investors in research, training, and demonstration projects for energy resource recovery as well as for planning for solid waste disposal;
- Linking charges to other utility services within the district
- Charging for dumping at landfill sites
- Adding charges to property rates so as to unify payment;
- Indirect charges through the sale of polythene bags for waste disposal [17].

Recycled polymeric material can be reused which saves production energy and prevents the dumping of materials into the environment. During the last decade, the mechanical recycling industries have showed an encouraging trend i.e. a 7% annual growth in Western Europe [2]. Unfortunately, the recycling rate varies regionally, and globally, and only a small percentage of total plastics waste is currently being recycled. In most countries, the form of plastic that are recycled is largely limited to bottles and drink containers [14]. Most consumers are keen to recycle and support for recycling is often very high in most western countries. However, the differences in symbols printed in different forms of plastic to describe recyclability of the object vary considerably among countries or regions and is often an obstacle to convenient recycling. This is why, in most countries, all kinds of plastic waste are collected together and is sorted at special stations before being recycled.

i. Energy Recovery

Plastics are almost all derived from oil wastes which are of a high calorific value. Energy recovered from plastic waste can make a major contribution to energy production. Plastics can be co-incinerated with other wastes or used as alternative fuel (e.g. coal) in several industry processes (cement kilns). The energy content of plastic waste can be recovered in other thermal and chemical processes such as pyrolysis. As plastic waste is continuously being recycled, they lose their physical and chemical properties at their end- of-life cycle. Continuous recycling could lead to substandard and low quality products. Hence it would no longer be economically profitable to recycle any longer [17]. Incineration with energy recovery would be the economically preferred option at this stage.

J. Conversion of Plastics Waste into Liquid Fuel

A research-cum-demonstration plant was set up at Nagpur, Maharashtra for conversion of waste plastics into liquid fuel. The process adopted is based on random de-polymerization of waste plastics into liquid fuel in presence of a catalyst. The entire process is undertaken in closed reactor vessel followed by condensation, if required. Waste plastics while heating up to 2700 to 3000 oC convert into liquid-vapor state, which is collected in condensation chamber in the form of liquid fuel while the tarry liquid waste is topped-down from the heating reactor vessel. The organic gas is generated which is vented due to lack of storage facility. However, the gas can be used in dual fuel diesel-generator set for generation of electricity [17].

k. Plasma Pyrolysis Technology

In plasma pyrolysis, firstly the plastics waste is fed into the primary chamber at 8,500 ^{o}C through a feeder. The waste material dissociates into carbon monoxide, hydrogen, methane, higher hydrocarbons etc. Induced draft fan drains the pyrolysis gases as well as plastics waste into the secondary chamber, where these gases are combusted in the presence of excess air [154]. The inflammable gases are ignited with high voltage spark. The secondary chamber temperature is maintained at around 10,500 ^{o}C. The hydrocarbon, carbon monoxide and hydrogen are combusted into safe carbon dioxide and water. The process conditions are maintained so that it eliminates the possibility of formation of toxic dioxins and furans molecules (in case of chlorinated waste) [154]. The conversion of organic waste into nontoxic gases (CO_2, H_2O) is more than 99%. The extreme conditions of plasma kill stable bacteria such as *Bacillus stereothermophilus* and *Bacillus subtilis* immediately. Segregation of the waste is not necessary; as very high temperatures ensure treatment of all types of waste without discrimination [154].

l. Legislative Measures

Creation of more legislative bodies such as which the United Nations Agency and the International Maritime Organization (IMO) introduced the marine pollution (MARPOL) convention in 1983, an international protocol to prevent and reduce pollution from ships. The protocol is referred to as MAEPOL 73/78, from the fact that the convention was signed in 1973 and the protocol was added in 1978. The protocol has been approved by 169 countries, which together are responsible for 98% of the world's total shipping pollution by preventing ships to release garbage, and totally prohibits the disposal of plastics anywhere into the sea. Further, it obligates governments to keep terminal facilities and harbors clean of garbage [155]. According to the terms of this agreement, every ship having a weight over tool and able to carry more than 14 persons is obligated to maintain a Garbage record book, in which records of all disposal operations will be kept. Information requires includes date, time, position of the ship and description and estimated amounts of garbage that is incinerated or discharged. In addition to maintaining a Garbage Record Book, marines are asked to prepare a garbage management plan that gives produces for collecting, storing and processing on board waste [155].

5. Conclusions

Due to ingestion or entanglement in plastic debris, over 270 species, including turtle, fish, seabirds, and mammals, have experienced impaired movement, starvation, or death [54, 156]. The important thing to do on the effect of plastics on aquatic ecosystem is to ban the input of plastics into the ocean or marine environment. Due to too much of dumping of plastics on marine environment, hundreds of species such as turtles, fish and mammals have experienced impaired movement, starvation, and death. Plastics do not disappear and will remain in our environments, definitely affecting wildlife, until the pollution is reduced. To avoid the death of some marine species plastics should be prevented from entering the ocean. Strategy to ensure that materials are recycled or disposed of properly need to be developed.

Recycling is the current solution that will make plastics not to be entering ocean. Plastics contain chemicals that can be harmful to marine organisms. Education is particularly important, because it is the basis for teaching the next generation to be aware of, and address the consequences of discarding plastics and other debris into the world oceans. With the evidence available, it is possible at presents to draw any sound conclusions on the direct risks posed by the occurrence of micro plastics particles in the marine environment or the influence of micro plastics on the risk posed to environmental and human health when associated with hazardous substances such as additives.

Plastics do not disappear and will remain in our environments indefinitely affecting aquatic life, until the pollution is reduced. Water is something every living organism on this planet cannot live without. If this resource is so precious that life cannot exist without it, we shouldn't be contaminating it [157].

The following are recommended as remedies for plastic pollution in the aquatic environment.

1. Development of indigenous and homegrown technologies for plastic waste management.
2. Development of quality standards and implementing them for all plastic recycled products.

3. Constant information exchange on best available practices and technologies.
4. Bye-laws on plastic waste management should be enforced.
5. Local communities should be made aware of the health and safety aspects of all levels of plastic waste recycling.
6. Policy formulation and implementation for plastic waste management should consider the needs of all levels of the community. The social responsibility for plastic waste management should be initiated at all levels of our education system, right from the primary school level upwards.
7. As much as possible plastic packaging materials should be replaced with foil-coated paper.
8. During waste disposal, plastic materials should be separated from other waste and treated appropriately.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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