

Review

Assessment of Microplastic Impacts in the Marine Environment: A Review

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Abstract: Threats emerging from microplastics pollution in the marine environment have received much global attention. This review assessed sources, fate, and impacts of microplastics in marine ecosystems and identified gaps. Most studies document ubiquity of microplastics and associated environmental effects. Effects include impacts to marine ecosystems, risks to biodiversity, and threats to human health. Microplastic leakage into marine ecosystems arises from plastic waste mismanagement and a lack of effective mitigative strategies. This review identified a scarcity of microplastics mitigation strategies across different stakeholders. Lack of community involvement in microplastic monitoring or ecosystem conservation exists due to limited existence of stakeholder co-management initiatives. Although some management strategies exist for controlling the effects of microplastics (often implemented by local and global environmental groups); a standardized management strategy to mitigate microplastics in coastal areas is urgently required. There is a need to identify focal causes of microplastic pollution in the marine environment through further environmental research. This would extend to creating more effective policies as well as harmonized and extended efforts of educational campaigns and incentives for counteraction and plastic waste reduction, while mandating stringent penalties for polluting the marine environment. This will help reduce microplastic leakage into the environment.

Keywords: impacts; microplastics; marine environment; single-use plastics; co-management initiatives

1. Introduction

Plastic pollution has become a growing global problem because of their persistence and impacts on the marine environment [1, 2]. Plastic production has increased 20-fold since the first mass production [2]. Irrespective of efforts reduce or remove plastic litter in marine ecosystems, plastic pollution continues to rise [2,3]. An estimated 12 billion metric tons (MT) of plastic waste is predicted to have been generated by 2050 [4,5]. Mismanaged plastic waste may eventually leak into oceans [6], where they persistent and degrade into microplastics (<5 mm) [7].

Considering the massive inputs of plastic debris into marine ecosystems it is not surprising that microplastics are now ubiquitous in marine environments. For example, microplastic hotspots have been measured in ten estuaries in northwest England [6]; plastic (>5 mm) and microplastic (<5 mm) debris from 25 beaches along Hong Kong coastline with more than 90% of the samples consisting of microplastics [8]. Also, multiple

microplastic hotspots with a maximum microplastic concentration of approximately 517,000 particles m⁻² were identified in northwest England [9] as well as >700 particles per kg dry sediment on the Scilly Islands in the United Kingdom [10]. Ebro surface water accounted for input of 2.14×10^9 microplastics yr⁻¹ to the Mediterranean Sea [11]. African coastal waters also have a high microplastic concentrations [12, 13, 14].

Microplastics have extended residence time, persistent and can adsorb other contaminants [15, 16]. Microplastics comprise microbeads from primary sources or several fragmented macroplastics (secondary sources) [17, 18]. Micro(plastics) comprise of monomers formed in a process called 'polymerization' [19]. Plastic polyethylene is formed during polymerization of ethylene which can be molded and shaped to form plastic bags or packaging materials. Styrene monomers yield polystyrene, monomers of esters are polymerized to polyesters, vinyl (ethenyl) produces polyvinyl chloride (PVC) and polypropylene.

Microplastic pollution and negative impacts on the environment has been widely acknowledged as a global problem on marine biodiversity [2, 20]. Microplastic risk assessment within the marine environment continues to be an area of uncertainty due to limited information on the qualitative and quantitative risks of exposure and effects [21]. Environmental concerns of microplastics in the marine environment includes severe aesthetic, economic, and ecological impacts [22], and as an important global problem that affects marine organisms as well as humans [23, 24]. With the continued increased use of plastics and increase in plastic and microplastic pollution in coastal waters, it is important to change and review existing plastic production, use and waste management policies. Although policies to ban or tax plastics and/or alternative use of plastic products responsible for microplastics exist in some countries, similar policies are lacking in many developing economies or are not properly implemented or enforced. This study reviews the chemical composition and effects of microplastics in marine ecosystems, critiques policies and management of plastic waste and recommends strategies to ameliorate further microplastic pollution.

2. Chemical compositions of plastics

2.1. Breakdown and plastic degradation

Polyethylene bags and other plastic materials are persistent and if mismanaged may leak into lakes, rivers, and oceans where they persist for decades or hundreds of years [24, 25, 26]. Plastics are inexpensive, lightweight, flexible, moisture-resistant, strong, and possess durable properties with extensive commercial, industrial, medicinal and municipal applications making them prevalent in the marine environment. Plastics degrade by abrasive action UV degradation that lead to development of microplastics [27]. Plastic bags and other solid materials have low-value recovery, are very buoyant, non-biodegradable, and undergo photodegradation and fragmentation on exposure to sunlight, consequently rendering the sea as a sink for microplastics [28]. Microplastics in the marine environment are ubiquitous because of their ability to be transported long distances suspended in seawater or the seabed [29, 28, 30].

2.2. Chemical additives in microplastics—Phthalate Plasticizers and Flame Retardants

Plastic products contain chemical additives that are integrated into plastics during manufacture to alter polymer properties or facilitate production processes, but these additives can be separated because they are not chemically bound to the plastic material [31]. Classes of chemical additives include plasticizers, fire suppressants, colorants, reinforcements, heat stabilizers, light stabilizers, fillers, and biological protection. However, plastic additives of emerging concern are plasticizers and flame retardants [32]. Plasticizers, for example, are a type of chemical additive that is incorporated into plastics during the manufacturing process for flexibility and softening of the polymer, thus, allowing rigid plastics to be malleable. Although over a hundred PVC plasticizers are commercially available, the most commonly used class is phthalates [33]. Reports prove the occurrence of phthalates in aquatic environments [34]. Plastic materials containing about 35 to 917 tons of chemical additives with the majority from plasticized PVC are being discharged into

the global marine environment annually [31]. The most abundant phthalates detected in seawater is diethylhexyl phthalate (DEHP); others include dimethyl phthalate (DMP), diethyl phthalate (DEP), di-n-butyl phthalate (DnBP), benzylbutyl phthalate (BzBP), and di-n-octyl phthalate (DnOP) [34]. Possible toxicity of phthalates (particularly DEHP) and the aquatic environment and human health threats has been a topic of global debate, as they can leach from chemical additive containing-plastic products such as toys, tableware, drinkware, and cooking utensils, PVC water pipes, and intravenous bags used in hospitals [35, 36].

Flame retardants are a class of chemical additives incorporated into polymers during plastic manufacture to make the plastic product fire-resistant. Acrylonitrile butadiene styrene (ABS), for example, is regarded as an engineering plastic used in several electrical appliances. Acrylonitrile butadiene styrene is vulnerable to fire and smoke; therefore, flame retardants are added to most plastics to suppress this weakness [37]. Although polybrominated diethyl ethers (PBDEs) are listed in the Stockholm Convention as persistent organic pollutants (POPs), yet they are the most frequently used flame retardants. Like other plasticizers, they are toxic and have the potential to leach into aquatic environments [31] resulting in hormone-altering abilities and other ecotoxicological impacts in marine organisms [38]. Another group of flame retardants used in plastics that have been investigated and found to be present in seawater and marine biota is the organophosphate esters (OPEs) [32, 39]. Most microplastics, due to their porous polymeric matrix, mechanical properties, and hydrophobicity, are known to have high adsorption tendencies for many organic pollutants [40]. The smaller the polymer size the greater its adsorption capacity, resulting from increased surface area or adsorption sites.

POPs are characteristically non-biodegradable chemicals that bioaccumulate in many organisms, including humans, and biomagnify in the food chain [41]. They exhibit long-range transport, are carcinogenic, endocrine disruptors, and possess lengthy half-lives. Certain classes of POPs interact with microplastics and thus portend grave dangers to aquatic organisms. The list of POPs linked with microplastics includes chlordane, a highly persistent banned pesticide which still contaminates aquatic environments [42]; dichlorodiphenyltrichloroethane (DDT) a banned pesticide, frequently found in the marine ecosystem; lindane (γ -hexachlorocyclohexane, HCH), a highly potent insecticide recognized as POP by the Stockholm Convention [43]; Polycyclic aromatic hydrocarbons (PAHs), from partial wood combustion and other carbon compounds [44], as well as in coal power plants, electronic wastes, dump sites, and shipping activities [38]. They are washed from the atmosphere into oceans and other surface water bodies by rainfall or watercourses or by direct deposition. Several PAHs used in industry to produce plastics, pesticides, and dyes are lethal to aquatic species, even at minute exposure [45]; and polychlorinated biphenyls (PCBs), used in electronic components and transformer housings [19]. They find their way to aquatic compartments mainly via municipal dumps [38] and are carcinogenic and human antibody suppressants. Due to their high resistance to environmental degradation, POPs persist in aquatic ecosystems for a long time [46]. This, coupled with widespread distribution of microplastics, which readily adsorb and concentrate the POPs, increases potential biological and toxicological impacts of microplastics [47]. Chemical attraction of POPs to microplastics causes POP concentrations to be much higher on microplastics than in the surrounding environment [48, 49].

Microplastics in the environment are vectors for persistent noxious chemicals. Rochman et. al. [50] found polystyrene, polyethylene, polyethylene terephthalate (PET), polypropylene, and PVC, containing varying PAHs levels from beaches in San Diego, California. Polystyrene and polyethylene showed the highest PAHs concentrations, and then polypropylene. Similarly, Lee et.al. [51] found that polyethylene, polypropylene, and polystyrene had high capacities for the sorption of different PAHs, hexachlorocyclohexanes (HCHs), and chlorinated benzenes in seawater. A much earlier study [52] reported that pieces (10-50 mm) of polypropylene were able to absorb considerable amounts (4-117 ng/g) of toxic PCBs. Although pieces of polypropylene used in the study were larger than the microplastic size range; the size of the plastics used determined POP concentrations,

resulting in size-dependent toxicity for aquatic species [53]. Endo et al. [54] measured PCBs concentration as high as 18,700ng/g in microplastic pellets obtained from Osaka Bay, Japan. Plastic pellets collected from selected beaches in Greece recorded varying concentrations of POPs (PCBs, DDTs, HCHs, and PAHs) relative to the pollution occurring at each site [55].

3. Microplastics in aquatic environments

Microplastic pollution originates from manufactured products dumped or discharged into any aquatic environment either purposely or accidentally as well as transported to this environment through runoffs, drainages, sewage systems, and by the action of winds, commonly referred to as Marine debris/litter [56-58]. Microplastics in the aquatic environment could be from primary and secondary sources [59]. Primary sources include unintentional or deliberate dumping of microbeads, microfibers, micro-pellets, and other products as identified by UNEP [60]. The products originate from industrial operations waste, or derivatives from the erosion and plastic products including boards, tires, wheels. Secondary microplastics occur through the breakdown by the action of biophysicochemical forces including biodegradation, heat, oxidation, UV light, and mechanical forces [61, 62].

Microplastics in the environment can also be derived from land-based sources including dumping of marine garbage from domestic/municipal use along shorelines, discharge of untreated sewage, agricultural practices, coastal tourism, and recreation, amongst others. Due to lack of and insufficient or malfunctioning waste disposal; solid materials such as plastic, glass, metals, paper, rubber, textiles, processed timber, cigarettes, caps/lids, beverage bottles, and straws/stirrers are constantly discharged into the sea by increasing human population. The buoyancy of most plastic materials (e.g. synthetic polymers) often facilitates its particles to float which are often transported or washed ashore [63].

Ocean-based sources of microplastics include the dumping of discarded or misplaced or abandoned fishing gear from ships directly into the sea and disposal of garbage from ships. Globally, shipping garbage accounts for approximately 600,000 plastic containers daily [64]. In developing countries where adequate waste disposal is often lacking, volumes of plastic materials discharges are higher. Plastic debris at sea can also originate from natural phenomena such as tsunamis, hurricanes, extreme floods, and rain. For instance, the Japanese Tsunami marine debris in March 2011 flushed nearly 5 million tons of litter into the ocean [65].

Marine plastic pollution contributes to loss of aesthetic values of the aquatic environment and disruption of fishing and tourism activities [66, 67]. Plastic pollution also contributes to disruption of cultural ties to natural resources availability and sustainable recreational activities [68]. Removal of plastic waste from the environment is a huge socio-economic cost and financial burden costing millions of dollars annually and estimates of economic losses of marine ecosystem services exceed billions of dollars each year [69, 70]. Yet their accumulation in organisms and transport to the food chain level is such that is detrimental to human health and a call for societal awareness and combat.

4. Transfer, accumulation, and effects of microplastics in the food chain

4.1. Effects of microplastics on aquatic biota

Microplastics bioaccumulate at different concentration levels in the marine environment [7]. Microorganisms and fish have been reported to assimilate and metabolize Persistent Organic Pollutants (POPs), absorbed into microplastics. These include cases of PBDEs in the tissues of marine amphipod, *Allorchestes compresa*, and fish [23, 71] as well as physical injuries on the marine organisms. Microplastics with sharp edges can induce injuries to the gill tissue and intestinal tract [66].

On the IUCN Red List, about 17% of species enlisted as either threatened or near threatened, have both been affected by both entanglements by plastic rope and netting and ingestion by plastic fragments [2, 72]. Considering the impact of marine plastics and debris in general, Kühn et al. [73] used the word “smothering” instead of entanglement.

Microplastics play the role of assisting in the transfer of persistent organic pollutants and other contaminants or toxic substances from biota into the marine food chain [74]. The small-sized microplastic has been mistaken for food by organisms such as macroinvertebrates-(bivalves, mussels, shrimps, oysters), zooplankton, fishes, copepods, sea turtles, and birds, as well as whales [23, 75]. In the food web, particles of microplastic may pass through the courtesy of the predator-prey feeding relationship [76]. This intake of contaminated species is a route for the translocation of sorbed contaminants and additives from plastics into the tissues of aquatic organisms [77, 78]. It is also very likely that microplastic consuming species in the water bodies ingest more concentrated levels of chemical pollutants such as POPs than they would in water bodies free from these micropollutants [19]. The microplastics provide substrates for inhabitation by marine organisms evident in Sea skater (*Halobates*); an insect that lives in the sea-air interface of the open seas and carries out oviposition on microplastic particles [79]. The small-particle nature of microplastics encourages their transportation over long distances, thereby enabling the dispersal of marine species such as invasive and pathogenic organisms [79, 80]. An increasing concern related to microplastics is their entry into the food chain thereby causing human health risks through the ingestion of contaminated fish, shellfish, and filter feeders [21, 29, 81]. Some examples have been listed in marine fish, zooplankton, and mussel species (Table 1).

4.1.1. Fish

Fish regularly consume microplastics confirmed by presence of microplastics in their digestive contents [82, 83]. In Mondego estuary, Portugal, 157 microplastic fibers (96%) and fragments (4%) were extracted from the gastrointestinal tract of 120 fish [47]. Polyester, polypropylene, and Rayon were the prevailing polymer type found. Similarly, in Ashdod, Tel Aviv region in Israel, 92% of sampled rabbit fish contained microplastic particles with 62.5% of the fish having 10–99 particles per fish gut [84].

Furthermore, Pellini et al. [85] reported the dominance of polyethylene (PE), polypropylene (PP), and PVC in 95% of benthic flatfish from the Adriatic Sea contained microplastics in their gastrointestinal tract. Similarly, Liu et al., [86] confirmed desorption of additives from ingested microplastic in fish from seas around China with increased polybrominated diphenyl ethers (PBDEs) concentrations in the affected fish. Fish exposed to polyethylene and other chemical pollutants, bioaccumulate these toxic chemicals resulting in liver toxicity and pathology [87]. Fish and fishery products are a significant part of a healthy diet. As a source of cheap animal protein in the developing world, they contain several vital nutrients, omega 3 fatty acid and low saturated fat [88]. Potential human health implications subsist from incessant consumption of microplastic-accumulated. There is, therefore, a need to provide innovative and cost-effective approaches that could hinder microplastics from reaching the coastal waters.

4.1.2. Zooplankton

Planktonic organisms ingest plastic materials from ambient water mistaking them for prey [89, 90]. The 'mistaken prey' contains several hazardous chemicals that when ingested, may affect the ecophysiology of the organism [91]. This may include their feeding habit, cellular dysfunctions, molecular pathways, reproductive output, and respiratory functions. A study in Marseille Bay, France, evaluated phthalate concentration in zooplankton samples and observed concentrations of Di-n-butyl phthalate (DnBP) and diethylhexyl phthalate (DEHP) in the samples from one of the sampling locations (Cortiou) to reach considerable levels of 750 ng/g and 4000 ng/g respectively and all six analyzed phthalates were detected in the seawater samples with DEHP being the most abundant [32]. These findings are important as chemical additives present in low-trophic level organisms can easily traverse the entire food web.

4.1.3. Mussels

Mussels are economically important seafood and are globally consumed by humans daily [92]. However, they are filter feeders that can ingest small particles, therefore, making them prone to taking up excess fragments of substances-like microplastics as well as any pollutants in the water [93]. These, as well as their sedentary and bioaccumulative nature, put them in the frontline as one of the most useful bioindicators for water pollutants and microplastic pollution. An ecotoxicological study involving the 4 days (6h each day) exposures of blue mussels to polyethylene (HDPE) developed formations of granulocytoma in their digestive glands and lysosomal membranes destabilization [94]. An indication that the toxic pollutant, HDPE when found in the environment, may be adsorbed by organisms. Chemical pollutants have been linked with microplastic detected in Mussels sampled from marine ecosystems. A study by Endo et al. [54] identified the presence of polychlorinated biphenyls (PCBs) concentrations (11-1630 ng/g) in blue mussels (*Mytilus galloprovincialis*) collected from 24 sample stations around the coastline of Japan. The South African blue mussels were also found to contain PCBs concentrations of 14.48-21.37 ng/g [95].

Mussels can bioaccumulate pollutants in their organs. Concentrations of pyrene in the gills of blue mussels were observed to be much higher than concentrations in the microplastics themselves in a study by Deudero et al. [90], thus indicating their bioaccumulative nature. The increase in desorption of pyrene ingested by blue mussels in the study led to abnormalities, lethal effects on DNA, and indicated neurotoxic effects. Continuous consumption of harvested contaminated blue mussels could posit some potential human health implications through bioaccumulation in the human body.

Table 1. Impact of microplastics on marine organisms.

Species name	Effects	References
Blue mussel (<i>Mytilus edilus</i>)	Decreased feeding activity Formations of granulocytoma in their digestive glands and lysosomal membranes destabilization	[96] [94]
Blue mussel (<i>Mytilus edilus</i>)	Ingestion of resin pellets Ingestion and accumulation of Phthalic acid esters and organophosphate ester flame retardants and plasticizers accumulated in the zooplankton samples	[54] [32]
<i>Mytilus galloprovincialis</i>		
Zooplankton		
Blue mussels (<i>Mytilus galloprovincialis</i>)	Increased levels of absorption of PCBs leading to toxic effects. The increase in desorption of pyrene ingested by the blue mussels led to abnormalities, lethal effects on DNA, and indicated neurotoxic effects	[95]
Pelagic fishes and holothurians		
Copepod (<i>Calanus helgolandicus, C. cristatus, Euphausiapaacifica</i>)	Ingestion/reduced feeding, decreased reproduction rates, decrease in egg production.	[91, 97]
European flat oysters (<i>Ostrea edulis</i>)	Ingestion and abnormal respiration rates	[98]
Mussel	Cytotoxicity, decrease in phagocytic activity, and increase in lysozyme activity	[99]
Sea turtles (Cheloniidae)	Ingestion	[100]
Mussel, amphipods (<i>Allorchestes compressa</i>)	Ingestion/inspiration/formation of granulocytomas and lysosomal membrane	[93, 101-103]

	destabilization/vector for accumulation of POPs.	
Lugworm (<i>Arenicola marina</i>)	Ingestion/increase in metabolic rates, reduced fecal casts formation, fitness effects.	[98, 104]
Brown shrimp (<i>Crangon cragon</i>)	Ingestion.	[105]
Zebrafish (<i>Danio rerio</i>)	Found in fish tissues	[106]
Gooseneck barnacles (<i>Lepas</i> sp.)	Ingestion.	[107]
Zebrafish		
Zooplankton	Microplastics entered the embryos and larvae	[108]
Fish	Reduce survival of aquatic zooplankton; Penetrate blood-to-brain barrier and cause behavioral disorders in fish	[109]
Zooplankton (<i>Centropages typicus</i>, <i>Daphnia magna</i>)	Ingestion/decreased algal feeding/causes Immobilization	[110, 111]
Sea urchin	Detected in the digestive tract of embryos	[112]
Demersal (cod, dab, flounder/pelagic fish (herring and mackerel)	Ingestion	[113]
Oyster	Significant decrease in fertilization and embryo-larval growth deformities	[114]
Shore crab (<i>Carcinus maenas</i>)	Ingestion-uptake through gills	[115]
Bivalves (<i>Mytilus edulis</i>, <i>Crassostrea gigas</i>/<i>Macoma bathica</i>, <i>Mytilus trossulus</i>)	Ingestion and accumulation in soft tissues	[101, 116, 117]
Marine fish (<i>Pomatoschistus microps</i>, <i>Artemia nauplii</i>, <i>Danio rerio</i>, <i>Oryzias latipes</i>)	Ingestion. Liver inflammation, pathological and oxidative stress, lipid accumulation in the liver	[87, 118-120]
<i>Paracentrotus lividus</i>	Growth deformities	[121]
<i>Crassostrea virginica</i>	Ingestion	[122]
<i>Mytilus edulis</i>	Translocation to the circulatory system	[102]
<i>Nephrops norvegicus</i>	Retention Accumulation	[123]
<i>Semibalanus balanoides</i>	Ingestion	[124]
<i>Carcinus maenas</i>	Retention	[115]
Mysis sp.	Ingestion	[125]
<i>Arenicola marina</i>	No accumulation	
<i>Chironomus tepperi</i>	Reduced feeding habits and energy budget	[48]
<i>Tripneustes gratilla</i>	Significantly increased mortality	[126]
<i>Paracyclopsina nana</i>	Significantly reduced body width	[127]
<i>Palaemonetes pugio</i>	Development significantly delayed for 0.05 μm	[128]
<i>Mytilus galloprovincialis</i>	Significantly increased mortality by larger particles ($>75 \mu\text{m}$)	[129]
	Significantly increased number of dead hemocytes	[130]

4.2. Human health effects of microplastics

The potential risks of microplastics to human health as an emerging contaminant are in the early stages of investigation. There is evidence of obvious dietary exposure of humans to microplastics [6, 131]. Ingestion, inhalation, and dermal contact are the reported routes of exposure for the human population [36]. Microplastics, along with those found at the surface of the water, are known to be easily photo-degraded into finer particles that can be taken up by plankton [16]. These organisms are involved in the food chain by transferring these toxic plastic particles up the trophic level. This includes fish which are eventually taken up by humans [132] leading to carcinogenic effects, skin

irritations, and several organ dysfunctions. Some of the toxic substances released in plastic materials due to degradation include bisphenol-A, styrene, and phthalates. These substances induce neurotoxic or carcinogenic conditions in affected humans [36, 133]. Microplastics in the food chain can lead to a decrease in nutritional diet value and exposure to pathogens [16]. Incidences of microplastic in drinking water abound with various sources acclaimed to be responsible for its presence [134, 135]. The bioaccumulation of various persistent chemical contaminants results in lethal and deleterious conditions in human beings. Owing to the tremendous effects of these microplastics on ecosystems, marine organisms, and human health, countries have thought it wise to create workable policies including proper plastic waste disposal and/or an outright ban of plastic bags to eradicate the menace of plastic pollution.

5. Plastic bag policy interventions aimed at plastics reductions in the coastal ecosystem

Microplastic pollution with its ensuing negative impacts on the environment has been regarded as a global problem with a great impact on marine biodiversity [2, 20]. There have been increasing interventions for the decrease in the use of plastic bags in several dimensions (Table 2) to ensure they do not get to the coastal waters. This includes the ban of plastic bag sales, plastic bags charges, and taxes from plastic bags sellers [136]. While countries like Australia, North America, and the United Kingdom have enacted various local jurisdictions in the bans, partial bans, and fees for plastic bags, some countries in Europe have widespread interventions with an imposition of a fee per bag. Bangladesh, India, and South Africa have progressively introduced bans on plastic bag consumption [137, 138]. Some other African, Asian, and European countries have also developed plastic bag bans [139, 140].

In North America, while Canada has imposed bans or levies in two cities and six municipalities only, the U.S. has only four of such states [136]. Colombia in South America only made 2020 plans to curb plastic bag use by 80% and totally remove the plastic use after 5 years of 2020 implementation. Up till the moment, only Buenos Aires Province in Argentina has implemented total plastic bags ban in markets [141]. India and China have the largest plastic discharge into the ocean [142]. They banned the manufacture of extremely light plastic bags, China, specifically established a fee in 2008 which decreased plastic bag use to greater than 70% in supermarkets and reduced plastic bag use by 40 billion. This, however, did not stop hawkers and retailers from plastic use, hence, causing their widespread in the environment [143]. The Northern Territory, South Australia, and Tasmania have autonomously banned the use of plastic bags even when there has not been a national ban on plastics in Australia. Furthermore, South Australia introduced the 'Zero Waste' program in the state in 2008 decreasing the annual 400 million bags. Conversely, the enforcement of bans and levies, especially at national levels in some other countries remains difficult is yet to be implemented [144]. America uses about 25% of the plastics since their enactment in 2009, whereas 30% of plastic bags are used in San Francisco and Seattle, WA which illustrates the tendency of reduced tonnes of microplastics that could find their way into the coastal waters. Although New Zealand and Bangladesh have policies for plastic bags their impacts are yet to be seen [136]. Table 2 highlights some of the countries and cities with the different policies which have been put in place for curbing plastic pollution and their resultant outcomes.

Table 2. Examples of global plastic bag bans.

Country	Action Plan	Year	Policy	Aim	Enforcement	Penalties	Impacts
AFRICA							
Nigeria	Ban	2019	<p>Interventions are lacking generally but the country is under pressure from experts to ban the use of plastic bags since after Kenya passed their policy.</p> <p>The Plastic Bags Prohibition Bill has been passed by the Federal House of Representatives but has not been approved by the Nigeria Senate or passed into Act (Law).</p>	Plastic pollution mitigation	Not enforced	<p>Defaulters are liable to pay fines of Five Hundred Thousand Naira (₦500,000 or USD 1,290) or to imprisonment of up to three years or both penalties.</p>	<p>The Bill is declining. Although it has not generated any interest the impact would be enormous and eco-friendly</p>
Kenya	Ban	2017	<p>Implementation of a national ban on plastic bags; including the importation, production, distribution, and use of single-use bags.</p> <p>The implementation of the ban of plastic bags on the distributors and producers of single-use bags.</p>	<p>Environmental preservation, conservation, and protection.</p> <p>Solid waste management</p>	Enforced	<p>The considerable consequence for violating the law is a four-year prison sentence or a 40,000 KES (USD 376) fine.</p>	<p>Although the law has been undermined by the activities of smugglers, however, there has been a reduction rate of about 100 million plastic bags used yearly</p>
Togo	Ban	2011	An intervention in the ban on the production, importation, possession, and commercial use of non-biodegradable plastics.	Environmental Protection	-	<p>Defaulters pay fines ranging from 5 million to 10 million FCAF (US \$8517–17,035) or go to prison for terms between two months to two years.</p>	-
Benin	Partial Ban	2018	A ban on the production, importation, possession, and possession, and use	Environmental Protection and sanitation	Poorly enforced	<p>Defaulters are liable to a fine ranging from 5000–100,000</p>	<p>In effect. Too early to assess impacts.</p>

			of non-biodegradable plastics.		CFA francs (US \$9–170)	
Rwanda	Ban	2008	<p>A national ban on non-biodegradable plastic bags prohibiting the production, usage, importation, and sale of plastic bags.</p> <p>Visitors into the country are not allowed to bring plastic bags.</p>	Plastic pollution mitigation	Poorly enforced	<p>Fined, imprisoned, public confessions. Six months jail for Smugglers and one year for company executives.</p> <p>License suspension of stores.</p> <p>Dispossession of plastic bags from plastics producers and a fine of ten million Rwandan francs (USD 10)</p>
Ghana	Tentative Ban	2014	<p>There was an attempt to ban plastics but failed to implement</p>	Revenue generation for plastic waste management	Poorly enforced	<p>There is presently no law banning plastic bags production, importation, or usage.</p> <p>The government believes plastic manufacturers play critical roles in the economy hence working effortlessly on managing plastics instead of banning them.</p>
South Africa	Tax/ partial ban	2003	<p>Prohibition of Plastic carrier bags and plastic flat bags of less than 30 µm thick. Tax on thicker bags.</p>	<p>Revenue generation.</p> <p>Removal and phasing out harmful plastic products</p>	Enforced	<p>Levies. The levy was said to increase rise from 12 cents to 25 cents from April 2020</p> <p>Between 2018/19 the revenue generated from bag levies levy increased by R59 million (USD 3 million) to R300 million (USD 17 million).</p>
Morocco	Ban	2009 (Partial Ban). 2016(Full Ban)	<p>Ban of manufacture, distribution, and importation of plastic bags</p>	Plastic bag pollution halt	Poorly enforced	<p>Violators pay fines ranging from \$20,000 USD to over \$100,000 USD</p> <p>The government is ensuring that plastic bag alternatives are easily accessible.</p>
ASIA						
Bangladesh	Ban	2002	<p>The Bangladesh government banned the assembling, promoting, and</p>	Environmental protection and plastic pollution mitigation	Non-enforced	<p>Jail or a fine of TK50,000–10lakh</p> <p>Polythene has been continuously produced, traded, and utilized all</p>

				utilization of polyethylene packs of fewer than 55µm thickness. Jute fibers were used to replace polythene bags for packaging in 2010.		over the country. Dhaka plastic use increased from 1.74% in 1992 to 6.5% in 2014 in overall landfills. Lack of impacts is due to non-enactment of the law and lack of economical environment-friendly options.
Malaysia	Ban	2017	Ban on non-biodegradable plastic bags	Environmental protection and sustainability	Poorly enforced. Several warnings have been issued against traders in the Federal Territories	Customers charge for biodegradable plastic bags up to RM0.20. Fine of RM1000 for non-compliance for business owners, one year jail, cancellation of business license
Israel	Ban	2017	Banned distribution of lightweight plastic bags <20 µm	To cut plastic waste	-	Charges for bags between 20 and 50 µm in all supermarkets
China	Ban	2008	Banned the distribution of single-use plastic bags in grocery stores and shops around the country.	Decrease in plastic bag production	Enforced	Fines of 10,000 yuan summing up to 1,593 USD by any companies for any illegal plastic bag distribution. The NRDC estimates that China has seen a 66% decrease in plastic bag usage since the ban. Also, 600,000 regulators have been sent to grocery stores around the country to ensure compliance.
India (Karnataka)	Ban	2016	Its law targeted the ban of different single-use plastic items, including plastic dinnerware. This policy puts pressure on manufacturers,	Decrease plastic pollution	Non-enforced	Fines of Rs 500 in Kolkata, Rs 5000 in New Delhi The policy was first implemented in 2016, and studies on its impact have yet to be pronounced due to weak enforcement.

<p>consumers, and distributors</p> <p style="text-align: center;">EUROPE</p>						
United Kingdom	Tax	2015	UK stores began charging 5cent per single-use plastic carrier bag in October 2015. Consumers are allowed to bring reusable bags to avoid being charged for bags.	Economic and environmental benefits	Enforced	Levy on consumer (£0.05, around USD 0.06). Though, the plastic bag charge applies to any business that has more than 250 employees and voluntarily for smaller retailers in England
Germany	1991	Tax	Legislation passed to ensure that retail stores providing plastic bags pay a tax or levy.	Environmentally friendly	Enforced	5- or 10-Euro cents/bag. Following the EU announcement, lightweight plastic bags will charge 20 cents per bag
Denmark	1994	Tax	The legislation was passed that enforces plastic bag producers to pay tax based on the weight of plastic bags.	Environmental Protection	-	Plastic bags cost consumers between 37 and 65 US cents
Ireland	2002	Tax	Legislation passed to create a levy for the sale of plastic bags in retail stores.	To reduce plastic waste and the adverse effects	Enforced	The levy started at 15 Euro cents/bag in 2002, and 2007, the levy increased to 22 Euro cents/bag. The levy was increased to 44 Euro cents in 2009.
Netherlands	2016	Tax	A tax is payable for plastic bags. Exemption from the levy applies to bags used	To combat litter in the streets and the sea and prevent wastage of resources	Non enforced	25 Euro cents per bag is advised, but the rate is not enforceable.
						Plastic bag consumption has been declined by over 80%. Significant economic benefits for the UK Government to be realized from the regular £60 million decreases in litter clean-up costs and £13 million in carbon reserves.
						The reduction in the use of lightweight plastic bags
						Reduction in the single-use plastic bags
						Discarded plastic bags amounted to 0.13% of litter pollution in 2015 as compared to an estimated 5% in 2001.
						Ban resulted in 40% less of plastic bags

for food or preventing food waste.							
Bulgaria	2012	Tax	Tax for single-use plastic bags	Waste prevention and management	-	Tax for bags <25 µm in October 2012 at 15 stotinki per bag. It has increased to 55 stotinki.	Bag consumption more than halved in the first month of the tax
France	2017	Ban/Tax	Supermarkets and retail stores are prohibited from distributing free plastic bags	Plastic waste reduction	-	Tax of €0.04 (\$0.05 USD) per bag, rising to €0.07 (\$0.09 USD) in 2019	In effect. Too early to assess impacts.
NORTH AMERICA							
United States of America	2009	Tax	Washington, D.C was one of the prime cities in the USA to pilot the way to ending plastic pollution. The revenue realized was for the Anacostia River Clean Up and Protection Fund and reusable bag gifts to poor and aged communities in the city.	Curbing Plastic Pollution. Revenue generation	Enforced	A 5-cent tax on plastic bags	85% reduction in plastic bag consumption was achieved. The number of bags consumed daily by DC locals reduced to 3.3 million bags per month as against the initial 22.5 million bags per month.
San Francisco	2007. Amended in 2012	Policy	A policy was placed to use reusable bags by placing an additional 10-cent fee on single-use compostable or recycled paper bags that clients require at the departure.	Zero waste by 2020 and environmental stewardship	-	No bag fee	A decrease in plastic bag uses by 72% was achieved since the policy was implemented in 2010. The new ban was expected that plastic bag use is to reduce from 70% to 90%.
Boston, MA	2018	Tax and Ban	A dual approach of taxation and bans on single-use bags was implemented	Reduction of plastic waste	-	A tax of 5-cent	Over 350 million plastic bags that were utilized yearly were drastically reduced.
Seattle, WA	2012	Ban	Retail stores were banned from releasing single-use	To reduce plastic waste	-	A tax of 5-cent per bag.	There has been a 78% reduction in plastic bag use.

OCEANIA							
Canada	2016	Tax	Tax for all shopping bags	To reduce plastic bag use	Non-enforced	Walmart Canada began charging customers, a 5-cent fee	-
Australia	2011	Ban	Banned plastic bags include all single-use polyethylene polymer bags that are less than 35 microns thick. Citizens were encouraged to bring reusable bags when shopping.	To reduce plastic wastes and for a green ecosystem	Enforced	-	The ban eliminates 1/3 of plastic waste sent to landfills before the ban. It is estimated that 400 million bags are saved yearly. An 80% decrease within three months two biggest supermarkets were banned from the use of single-use plastics.
New Zealand	2019	Ban	Plastic shopping bags with a thickness of fewer than 70 microns were banned in July 2019 after the first pronouncement on 18 December 2018.	Plastic pollution mitigation	-	Defaulters are to pay fines up to £51,000.	The impact is yet to be seen
Papua New Guinea	2016	Ban	A nationwide ban on plastic bags.	Plastic pollution mitigation	-	Companies face K50,000 fine on plastics	The government promoted the use of traditional and locally manufactured bilum bags
SOUTH AMERICA							
Chile	2017(2018)	Ban	Ban on businesses that keep distributing plastic bags, and accompanied by government-coordinated beach cleanups, specifically during	Plastic waste reduction	Enforced	Fines of equal to USD 300	Some 80 municipalities have restricted plastic bag distribution, while some coastal and lakeside areas have banned plastic bags

			peak vacation times when most of the plastic waste is accumulated on the beach.			altogether. In late May 2018, major retailers were banned to use plastic bags while the smaller retailers were given a grace of two years to stop plastic use. Within the period, only two bags for each client.	
Brazil	2015	Ban	Ban on the distribution of plastic bags in supermarkets	To encourage biodegradable bags	Non-enforced	-	Lack enforcement to see great positive impacts
Colombia	2017	Ban	Ban on single-use plastics and bags <30 cm.	Reduce single-use plastics	-	A fee of 1 US cent	In effect. Too early to assess impacts.
Argentina	2012	Ban	The province of Mendoza in Argentina joined Buenos Aires in a ban on plastic bags	To discourage non-biodegradable bags	-	-	The use of biodegradable bags and boosts recycling incentives

While impacts are yet to be seen in some countries (Table 2), some other countries are even yet to formulate stringent policies and regulations for microplastics. Plastics have been seen as an indispensable commodity; since industries keep manufacturing them while end-users keep patronizing the products. It is, therefore, pertinent to re-evaluate the interventions and look for a sustainable approach to stopping plastic pollution.

5.1. Microbead ban interventions

Microbeads have progressively been manufactured (to substitute natural exfoliating materials, including pumice, oatmeal, and walnut husks) [81]. They are recently used in cleaning products, printer toners, plastic blasting, textile printing and automotive molding, and medical applications [145]. According to UNEP [29], cosmetics products contain higher concentrations of microbeads than the plastic container itself. Although microplastics are the most prevalent plastic in the ocean, however, about 8 trillion microbeads are released into effluent treatment plants daily. Thus, very difficult to remove them from aquatic ecosystems [146, 147].

Many countries in the continents have diverse interventions through taxes, bans, and policies to reduce or manage plastic bags, but there are few interventions for microbeads [136] (Table 3). The Canadian government classified these microbeads as toxic substances under the *Canadian Environmental Protection Act*. The increase in the use of such microbead-contained cosmetics in the 20th century has given the rise to the national bans of the sale and use of microbeads. Only a few countries have taken this step. For example, Canada has implemented to ban on single-use toiletries and cosmetics containing microbeads from stores on microbeads [148]. The province of Ontario passed legislation banning the manufacture of microbeads in 2015 [149]. The classification of microbeads as a toxin was initiated to develop microbead regulations, prohibit the manufacture, import, and sale of certain exfoliating personal care products [150].

The Netherlands was one of the first countries to announce its intention to exclude microbeads in cosmetics at the end of 2016 and to legislate to prohibit the import,

manufacture, and sale of microbeads in washable cosmetics [151]. The ban on the use of microbeads in rinse-off cosmetics and personal care products took effect in the United Kingdom-Environmental Protection (Beads) Regulations (England) 2017 [152]. The scope of this legislation in the United Kingdom far exceeds the "Bead-Free Water Act" passed by the US government in 2015 [153]. Unlike the United States and other countries that have loopholes in the legislation allowing the use of biodegradable plastics, the UK Ministry of Environment, Food and Rural Affairs has made it clear that the ban covers biodegradable microbeads [154]. Although materials can be labeled as compostable or biodegradable, they usually require specific conditions to decompose, and these conditions are not common in the deep ocean environment. Therefore, many plastic items will be broken down into small pieces, but not completely. China's National Reform and Development Commission issued a draft for public comment, that details China's pending microbead ban. China's proposed legislation will ban the production of new cosmetics containing microbeads by December 31, 2020 [155]. The sale of existing cosmetics containing microbeads will be banned before December 31, 2022.

Table 3. Examples of global microbead policy interventions.

Country	Year of ban	Policy	Purpose of Ban	Impact of the Ban
U.S. (National)	2015 (2017–2019)	The amendment of the Federal Food, Drug, and Cosmetic Act gave rise to the Microbead-Free Waters Act of 2015 to ban rinse-off cosmetics that contain intentionally added plastic microbeads beginning on January 1, 2018, and to ban manufacturing of these cosmetics beginning on July 1, 2017. Although the bans were delayed by one year for cosmetics that are over-the-counter drugs.	The ban was to oversee the manufacturing and importing of cosmetic products and over-the-counter medication that include synthetic microbeads.	From 2015, the State legislature passed legislation that was due to phase in a ban of synthetic microbeads in Colorado, Maine, New Jersey, Wisconsin, Indiana, Maryland, Connecticut, New York, California, Illinois among others.
Austria, Belgium, Sweden, Netherlands, Luxembourg (Multi-national)	2015	These countries issued a joint statement requesting a ban of microbeads in personal care products.	Protecting marine ecosystems including seafood from contamination	The countries forwarded their joint call on eliminating microbeads in cosmetics and detergent to the European Union's Environment Ministers. Some companies have shown commitment to stop using microplastics and microbeads in their products.
Canada (National)	2016 (2018–2019)	National ban of microbead products. Canada became the first country to list microbeads as a "toxic substance".	Aimed to ban the manufacture, import, and sale of products containing microbeads to be phased in during 2018 and 2019	The Ontario parliament passed legislation to ban microbeads in 2015. The legislation prevents the production of microbeads in Ontario. This ban is to commence in June 2017

5.2. Critiques in plastic and microbead ban interventions and way forward

Plastic bag and microbead intervention are significant enactments of policies and legislation [136, 156, 157]. The absence of statutory law formulated as well as weak and poorly enforced with inadequate compliance in most developing countries contribute to the continuous discharge of plastics and microplastics into the coastal waters. As there exist environmental regulations to monitor different environmental pollution, there should be specific environmental guidelines and standards that would guide plastic discharge and non-compliance of policies in countries. Therefore, this study is expected to be a launchpad for the development of microplastics control policies and legislation, especially in developing countries. Realistic discussions should be proposed to ensure a significant change in policies and implementation of existing ones. Existing laws on environmental pollution and the development of stringent plastic discharge regulations need to be strengthened. Plastic industries and firms responsible for production should be monitored or sanctioned where necessary.

Amidst the improved policies and regulations in some of the developed countries, works of literature have continuously elucidated the various effects of microplastics on biota and the environment [32, 85]. This explains that the government alone might not necessarily achieve the goal of eradicating microplastics in the coastal waters. Literature has exhibited a dearth of clarification on how the public could be involved in microplastics mitigation processes, where policies and plastic ban interventions become clumsy and unimplemented. More significant is the limited awareness of the public especially members of the rural coastal communities on the threats of microplastics and the viability of marine ecosystems. The understanding that some actions like plastic dumping pose risks to these ecosystems may improve dynamic public and communities' involvement in marine ecosystems protection from microplastics pollution [158]. There exists an overshoot by policymakers that the socio-cultural impact of microplastic pollution could be a central reason to solving the challenges of microplastic pollution [159]. Therefore, in-depth knowledge of the environmental fate and potential adverse effects of microplastics in aquatic environments is needed. With the increase in the microplastics and effects on the marine ecosystems, it is suggested that community and public vanguards could be initiated to develop a feasible platform for microplastics mitigation and ecosystem balance. Where the microplastics mitigation model is lacking, it will be difficult to monitor the ecosystem. Satisfactory data about the toxic effects of microplastic pollution and the moves to curb microplastics in most developing countries are still deficient [160].

Threats from this emerging toxic pollutant to the ecosystem and biodiversity are a dire need for continuous research. The local government, state government, federal government, coastal communities, regulatory agencies, and research institutes are significant stakeholders to take note of this emerging pollutant and all should be incorporated into the management team [158]. Adam et al. [157] indicated the use of stakeholders for a successful single-use plastic ban. Their study stated the need to engage stakeholders about the current and future policies to reduce single-use plastic in which adequate time is given before the announcement and implementation of such policies [157].

Microbeads-containing goods, organic toxic pollutants, and an enormous volume of recalcitrant plastic wastes dumping could be curbed and avoided into the coastal systems by necessary collaborations and stringent steps by the different stakeholders (Fig. 1). A contributory and co-management method has been used for mangrove conservation and restoration where the government, rural communities, and other stakeholders were involved in the restoration process [161]. For microplastics to be managed effectively, critical models or enabling conditions should be created. The model should introduce a contributory approach that would allow a wide range of stakeholders that could add to a robust mitigation process. With this method of designing a model, each stakeholder will own an initiative, roles, and eventually support and partake in the mitigation process. We, therefore, propose a co-management model for active participation of microplastics mitigation from our coastal waters. The proposed co-management model is expected to

proffer lasting solutions for microplastic pollution. The specific roles of the stakeholders for feasible microplastics mitigation have been highlighted in the model (Fig. 1).

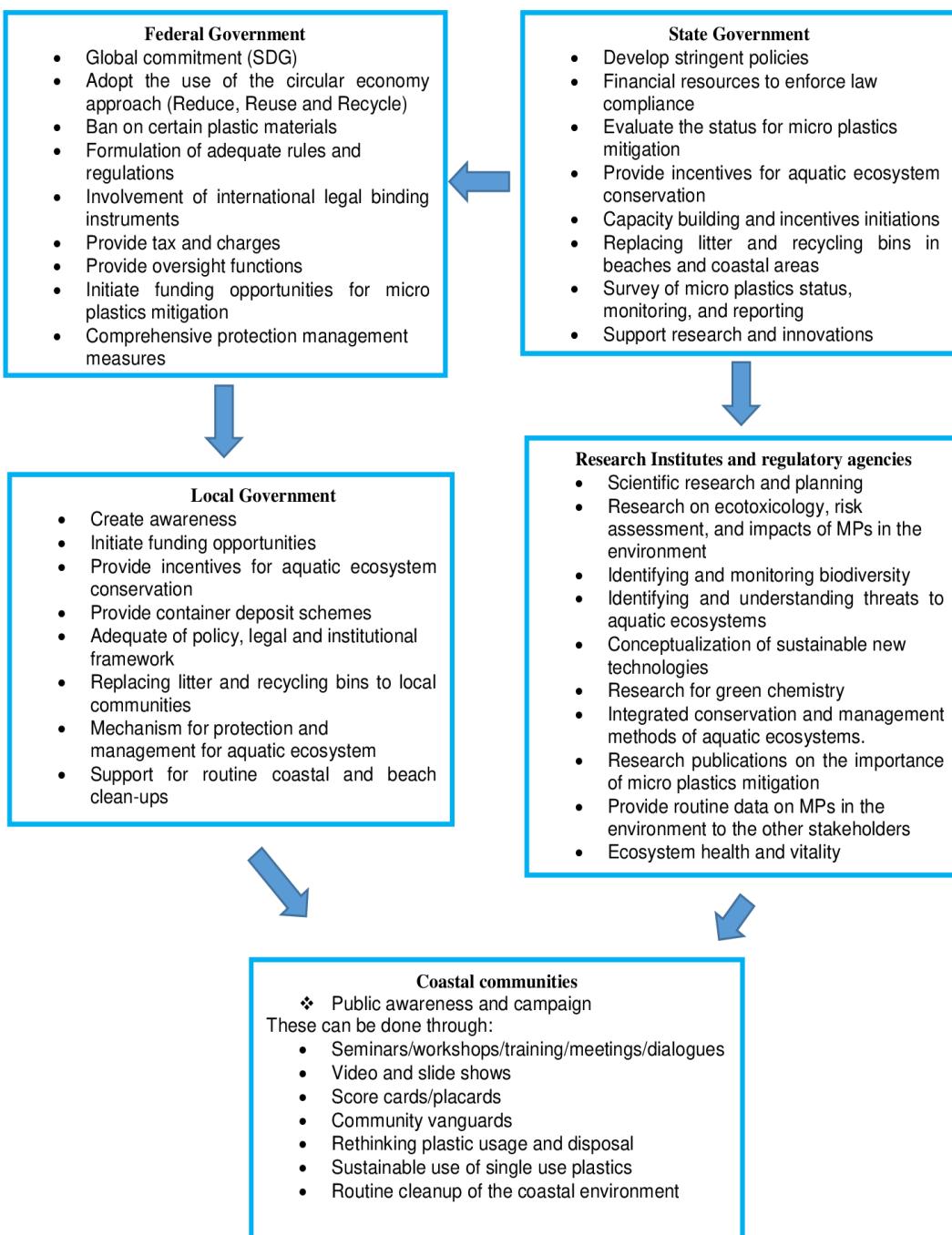


Figure 1. Proposed co-management model for microplastics mitigation.

Furthermore, research directions regarding microplastics pollution should include evaluating the distribution, occurrence, variations, and source discovery of microplastics in environmental samples especially with the macroinvertebrates (the more impacted organism groups). Ecotoxicological risk assessment of microplastics should be evaluated as concerns their absorptions, period of exposures, and trophic level transfer as well as the characterization of microplastics and gene expression in aquatic organisms. There is also a need for a stringent national action plan vis-à-vis the management and assessment of microplastics from the point sources.

6. Governance approaches and Management practices for microplastics pollution

Microplastic pollution proves significant governance challenges given the related risks and ubiquity of microplastics in the marine environment [162]. Microplastics are the topmost problems of international significance that affect ecosystems and habitat, marine species, and resources in addition to the global ocean and coastal communities [163, 164]. It has thus progressively become a transboundary issue that needs absolute priority mitigation considerations and attention from different stakeholders [162].

6.1. Governance approaches to microplastics pollution

Several governance strategies are apt to curb plastics use and avert marine environmental pollution [162]. In the last few years, microplastics pollution has attained substantial attention from researchers and the public, yet there exists a significant gap in developing a clear policy and governance mitigation response [165]. Efforts to tackle microplastics globally have been restricted to weak and fragmented acts [166]. Addressing the microplastics problem is crucial for accomplishing and actualizing sustainable ocean governance and the 2030 Sustainable Development Goals ([SDGs] [167]). A co-management model from the international and complementary governance by non-state actors is important to efficiently prevent microplastic pollution from flowing into the oceans. The ubiquity nature of microplastics thus places it in such a way that they have no restrictions to reach any continental borders and thus exceed their limits of the national jurisdictions. As such, there have been demands for over 20 years for participatory and co-management actions to find global solutions for this transboundary challenge [162].

Continuous international cooperation is needed to unravel this transboundary issue [162]. Nevertheless, the global collaboration required remains fragmented and reflects the extremely decentralized nature of the international system [164]. In most cases, the international plans are not bound in the formal legal sense notwithstanding the amplified global awareness and various tactful plans to develop joint solutions [168]. The United Nations Environment Assembly emphasizes the need for the prevention of microplastic pollution in the marine environment and boosts nation-states to create national and regional marine litter act strategies [169]. The SDGs formed by the United Nation show the necessity to place microplastic pollution governance as an environmental justice issue, as it affects biodiversity, national and global livelihoods, resource availability, and other global environmental problems [170]. Among the SDGs connected to plastic governance include Clean Water and Sanitation of SDGs 6, Sustainable Cities and Communities of SDGs 11, Responsible Consumption and Production of SDGs 12, and Life Below Water of SDGs 14. Similarly, the London Dumping Convention and Annex V of the MARPOL 73/78 act are intended to reduce direct pollution dumping from boats and ships into marine ecosystems. The UN Convention of the Law of the Sea (UNCLOS) Part XII is designed by its ability to protect and conserve the marine environment and involves states to ensure the prevention, reduction, and control of pollution in the marine ecosystems from any sources. Notwithstanding these contemporary international cooperation efforts, there has not yet been an international action plan adequate to tackle the booming concentrations of microplastics in the environment [162]. However, as we enter the Ocean Decade (2021-2030), there is a need to take a comprehensive global inventory of the diverse pertinent governance and management strategies that have emerged in recent years from local to continental scales, discussing how governance entities can negotiate and implement the rules that govern ocean use and the consequent effects for ecosystem sustainability [171].

Discrepancies between the directives and actions of government agencies deter collaboration and communiqué essential for implementing wide-ranging management plans [171]. There is a need to align policies and legislation across levels of government and international organizations to enable integrated ocean governance and create synergistic beneficial solutions and exploit the environmental and socioeconomic benefits from ocean use [171]. It is therefore imperative for collaborations from environmental stakeholders and scientists to address environmental pollution challenges for a better policy harmonization [172]. Lessons learned from situations where science uptake to decision-making

has helped to steer environmental challenges, which can build mutual poise for a co-management framework [173]. Participatory governance methods are at the forefront, therefore, a cross-sectoral method, improved collaboration, defined contributory framework, harmonization, and policy consistency in ocean governance is needed to attain the implementation of lasting and robust methods to reduce microplastics in the environment [162]. Scientists, government, and governance researchers will need to utilize a structured laboratory management model as proposed in this review (Fig. 1) to support SDGs and alleviate microplastics in the environments and marine ecosystems.

6.2. Management of microplastics and plastic debris

A sustainable approach to both production and consumption of plastic materials with global efforts has been geared towards the management of marine debris via prevention. The United Nations Environment Assembly (UNEA-2) of 2016 and 2017 indicated that more countries have seen plastic debris and microplastics as global concerns in need of a global response [174]. The upstream measures of preventing the sources of plastic materials in the marine environment are more cost-effective than the focus on downstream clean-up exercises [21].

The translation of global commitments such as the Sustainable Development Goals (SDGs) to regional and national levels, with support from scientific research relevant to local communities, can form the basis for successful plastic debris management [21, 174]. Risk assessments of various regions can be used to predict global hotspots of plastic/microplastics prevalence in the marine environment, and well-defined protection goals meted out, especially for the sustenance of biodiversity [2, 175].

The social slogan of “3Rs: reduce, reuse and recycle” used in the management of most wastes found in the environments has continuously been implemented in the case of plastic wastes, more so to traditional plastics whose long carbon chains make them difficult to degrade or be broken down by microorganisms [176]. The 3Rs are what Lohr et al. [174] reported as a circular economy approach as a means of a sustainable long-term solution, from the existing linear economy. Upcycling (reuse), which is the art of recycling to improve a material’s value, and redesigning of products to make them less hazardous, as well as improved producer responsibility are also means of sustainable management of plastic wastes [177]. Open landfills and dumpsites seat a considerable amount of plastic waste that is often flushed into the ocean during rains. Recycling and reusing plastic products are some of the most effective actions to reduce the volumes of plastic wastes that must be flushed into the ocean. In improving recyclable plastic material wastes, chemical recycling has been considered as a sustainable alternative in the past decade, i.e. the collection of used plastics and chemically recycling them into raw materials for brand-new plastic production of the same properties as the original, and avoiding the incidence of new monomer feedstock [178]. The methods that have been employed in chemically recycling plastic material wastes involve directly converting them into products with a higher yield. This can be seen in the preparation of elevated yield of aryl ether sulfones which involves the depolymerization of polyesters and aromatic polycarbonates into bisphenol-type monomers or depolymerizing plastic wastes back into a starting product and thereafter, depolymerized to produce poly(g-butyrolactone); virgin-like plastics can be quantitatively depolymerized through heating the bulk product into the original g-butyrolactone [179, 180]. The present consequence of depolymerizable plastics is that they are limited in mechanical and thermal properties, which also reflect in their usage [179].

The quest for (marine) environment-friendly plastics gave rise to green plastics (green chemistry) [36]. Green plastics involve the use of biodegradable plastics. Among the considered perspectives toward sustainable plastic production and curbing plastic wastes; commodity polymers can be made through the use of monomers from plant sources or by producing an alternative to fuel-based products from plant-based polymers [181]. Hence, in reducing the number of chemicals used in the manufacture of plastics by incorporating bio-products; alternatives such as citrates can be used as a substitute for plasticizers [36]. Also, zeolites can be used to produce sustainable plastics from

biologically sourced feedstock; a zeolite-based approach catalyzes the transformation of lactic acid into lactide. The microbiologically produced lactide is a precursor of biodegradable polylactic acid plastics, but this is not easy to synthesize, and the active site spatial confinement in the zeolite micropores mainly determines its selectivity [182].

Consequently, the durability quality of plastics is the basis for their use in some applications; and biodegradable plastics pose the question of maintaining similar mechanical integrity and durability required within their lifetime of usage. Therefore, some of the known complete biodegradable plastics in the marine environment include aliphatic polyesters and biopolymers [21].

More also, to prevent plastic debris, prevention, legislation, and market-based instrument have shown certain levels of effectiveness in curbing plastic wastes in developed and developing countries; such as the bans on certain plastic materials (e.g. plastic bags), tax and charges, container deposit schemes [174, 183]. Legal efforts made at the international and national levels to monitor marine pollution are faced with non-compliance of the laws partially as a result of a lack of financial resources to enforce them. Also, Lohr et al. [174] pointed out that lack of monitoring, enforcement, and possible difficulty with some legal frameworks due to political incitements may result in setbacks. It is, therefore, required that existing international legal binding instruments should be considered to tackle plastic pollution. There is a need for co-management and collaborations among the governments, research institutions, and industries in redesigning materials, and rethink their usage and disposal techniques, to reduce microplastics waste from pellets, synthetic textiles, and tyres. This includes understanding the compositions of plastic materials, design of products for infrastructure and household use.

In addition, research and innovation need to be supported for effective microplastics mitigation. The understanding of plastic pollution and its effects would provide manufacturers, consumers, policymakers, and stakeholders with the scientific proof needed to spearhead appropriate technological, behavioral, and policy solutions. It would also increase the conceptualization of new technology and products to replace plastics. Government sectors could combat the problem of microplastics by improving the awareness of microplastics as well as providing incentives to individuals [184]. Global concern and awareness through education are crucial to improve ecosystem balance and probably effectively change the 'throw-away' habits of people, especially starting from childhood [185]. Organizing seminars and conferences to educate the public on the need to care for the environment and how to properly care for them after and during leisure activities on beaches would be helpful.

Programs to recycle fishing nets and improved waste management facilities for fishing or shipping wastes at ports and harbours should be implemented [186, 187]. Programs to support retrieval of abandoned, lost or discarded fishing gear should be implemented across different jurisdictions which can have both positive economic and conservation impacts via reduced by-catch of target and non-target species [188]. Schools are important centres for learning about recycling and conservation of the marine environment by incorporating these concepts into study programs and encouraging participation in citizen science beach cleanup activities to raise awareness [184, 189]. Appropriate waste disposal and recycling facilities should be widely available in cities, and along beaches to reduce plastic pollution in coastal areas. This review highlights some of the roles and responsibilities for all stakeholders to prevent and control leakage of microplastics in the marine environment to help ensure coastal sustainability.

7. Conclusion and recommendations

Microplastics are globally abundant, ubiquitous, and persistent. Coupled with increasing levels of aquatic chemical pollutants, that can be readily sorbed and concentrated onto microplastics, which can be consumed indiscriminately by aquatic organisms, poses a serious threat requiring global action. Chemical pollutants sorbed to microplastics and chemical additives incorporated during plastic manufacture can leach from microplastics into aquatic biota tissue and can bioaccumulate across higher trophic levels and even

humans. Research on toxicity of microplastics to biota is in its infancy and impacts to human health from consumption of seafood containing microplastic remains unclear. It is also important to raise awareness of the impacts of microplastic and plastic waste mismanagement for all stakeholders. Stringent policies are required at local, national, regional and international levels to reduce use and consumption of plastics and to provide incentives for plastic pollution prevention and waste reduction.

The following areas are recommended for future research:

- How do chemical pollutants leach from microplastics once ingested become absorbed into tissues of aquatic organisms?
- More studies on ecosystem level impacts of microplastic pollution using multiple species and trophic levels are required rather than laboratory studies on single species.
- More studies on biomagnification of chemical pollutants associated with ingested microplastics and the impact on higher trophic levels, especially humans are required.
- Long-term monitoring to further characterize microplastics and establish their interactions with persistent organic pollutants.
- More studies on the fragmentation of microplastics into nanoplastics are required, as nanoplastics could have more detrimental size dependent effects on aquatic organisms.
- Continued and re-assessment of community and government strategies for plastic waste reduction.

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