Governance Strategies for Mitigating Microplastic Pollution in the Marine Environment: A Review

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Abstract: Threats emerging from microplastic 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 the 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 from different stakeholders. Lack of community involvement in microplastic monitoring or ecosystem conservation exists due to limited existence of citizen science and stakeholder co-management initiatives. Although some management strategies exist for controlling 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 review policy interventions aimed at plastic reduction in or near coastal ecosystems and evaluate their effectiveness. There is also a need to identify focal causes of microplastic pollution in the marine environment through further environmental research and governance approaches. These would extend to creating more effective policies as well as harmonized and extended efforts of educational campaigns and incentives for plastic waste reduction while mandating stringent penalties to help reduce microplastic leakage into the marine environment.

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

1. Introduction

Plastic pollution has become a growing global problem because of its persistence and impacts on the marine environment [1,2]. Plastic production has increased 20-fold since the first mass production [2]. Irrespective of efforts to 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 it persists and degrades 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 10 estuaries in northwest England [6]. More than 90% of samples from 25 beaches along Hong Kong’s...
coastline comprised of microplastics [8]. Additionally, 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 of dry sediment on the Isles of Scilly in the United Kingdom [10]. Ebro surface water accounted for the input of $2.14 \times 10^9$ microplastics yr$^{-1}$ to the Mediterranean Sea [11]. African coastal waters also have high microplastic concentrations [12–14].

Recently, huge amounts of plastic waste, especially medical waste and single-use plastics, have been generated during the current global COVID-19 pandemic [15]. This has exacerbated the 19–23 million metric tons of plastic pollution estimated to have entered marine and aquatic ecosystems in 2016 [16]. Such predictions are attributed to the continued excessive use and consumption of single-use plastics (including personal protective equipment (PPE), such as masks and gloves due to the prevailing global COVID-19 pandemic) [17,18].

Microplastic pollution and negative impacts on the environment have been widely acknowledged as a local and global problem on marine biodiversity, economic activity, and human health [2,19,20]. 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 include 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 longer [24–26]. Plastics are inexpensive, lightweight, flexible, moisture-resistant, and 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 and UV degradation that leads to the development of microplastics [27]. Plastic bags and other solid materials have low-value recovery, are very buoyant and non-biodegradable, and undergo photodegradation and fragmentation on exposure to sunlight, consequently rendering the sea a sink for microplastics [28]. Microplastics comprise microbeads from primary sources or fragmented microplastics (secondary sources) [29,30]. Microplastics are comprised of monomers formed in a process called ‘polymerization’ [31]. Plastic polyethylene is formed during the 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, and vinyl (ethenyl) produces polyvinyl chloride (PVC) and polypropylene. Microplastics in the marine environment are ubiquitous because of their ability to be transported long distances suspended in seawater or the seabed [28,32,33]. They have extended residence time, are persistent, and can adsorb other contaminants [34,35].

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 [36].
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 [37]. Plasticizers are chemical additives that are incorporated into plastics during manufacturing for flexibility and softening of the polymer, thus allowing rigid plastics to be malleable. Although hundreds of PVC plasticizers are commercially available, commonly used plasticizers such as phthalates are frequently detected in aquatic environments [38,39]. The most abundant phthalate 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) [39]. Potential toxicity of phthalates (particularly DEHP) on aquatic and human health has been widely debated. Phthalates can leach from plastic products such as toys, tableware, drinkware, cooking utensils, PVC water pipes, and intravenous bags used in hospitals [40,41].

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 [42]. Although polybrominated diethyl ethers (PBDEs) are listed in the Stockholm Convention as persistent organic pollutants (POPs), they are the most frequently used flame retardants. Like other plasticizers, they are toxic and have the potential to leach into aquatic environments [36], resulting in hormone-altering abilities and other ecotoxicological impacts in marine organisms [43]. 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) [37,44].

Most microplastics, due to their porous polymeric matrix, mechanical properties, and hydrophobicity, are known to have high adsorption tendencies for many organic pollutants [45]. The smaller the polymer size the greater its adsorption capacity, resulting from an increased surface area or adsorption sites [46].

POPs are characteristically non-biodegradable chemicals that bioaccumulate in many organisms, including humans, and biomagnify in the food chain [47]. 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 [48], dichlorodiphenyltrichloroethane (DDT), a banned pesticide frequently found in the marine ecosystem, lindane (γ-hexachlorocyclohexane, HCH), a highly potent insecticide recognized as a POP by the Stockholm Convention [49], and Polycyclic aromatic hydrocarbons (PAHs), from partial wood combustion and other carbon compounds [50], as well as in coal power plants, electronic wastes, dump sites, and shipping activities [43]. They are washed from the atmosphere into oceans and other surface water bodies by rainfall or watercourses or by direct deposition [51,52]. Several PAHs used in industry to produce plastics, pesticides, and dyes are lethal to aquatic species, even at minute exposure [53]; polychlorinated biphenyls (PCBs) are used in electronic components and transformer housings [19]. They find their way to aquatic compartments mainly via municipal dumps [43] and are carcinogenic and human antibody suppressants. Due to their high resistance to environmental degradation, POPs persist in aquatic ecosystems for a long time [54]. This, coupled with the widespread distribution of microplastics, which readily adsorb and concentrate the POPs, increases the potential biological and toxicological impacts of microplastics [55]. The chemical attraction of POPs to microplastics causes POP concentrations to be much higher on microplastics than in the surrounding environment [56,57].

Microplastics in the environment are vectors for persistent noxious chemicals. Rochman et al. [58] 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 polypropy-
microplastics. Similarly, Lee et al. [59] found that polyethylene, polypropylene, and polystyrene had high capacities for the sorption of different PAHs, hexachlorocyclohexanes (HCHs), and chlorinated benzenes in seawater. An earlier study [60] reported that 10–50-mm polypropylene fragments were capable of adsorbing 4–117 ng/g of PCBs. Thus, toxicity was reported for polypropylene fragment sizes that were greater than microplastics (<5 mm) [61]. Endo et al. [62] measured PCBs’ concentration as high as 18,700 ng/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 [63].

2.3. Microplastics’ Contamination and Metal Adsorption

Global contamination of aquatic ecosystems by microplastics is an emerging environmental and health issue. To worsen this, microplastics adsorb and accumulate other aquatic pollutants such as metals [64,65]. The adsorbent feature of pollutants by microplastics affects their fate and toxicity in the environment [66,67].

Metals are considered as soluble toxic pollutants that have overextended periods in aquatic systems [68]. Metal adsorption on microplastics occurs through complex mechanisms [69]. They enter aquatic ecosystems and are transferred and accumulated through physicochemical and biological factors. Inorganic minerals and organic compounds precipitate on the surface of plastic particles, leading to the alteration of their surface properties and formation of various active bindings of different metals [70]. Microplastics may be ingested by marine organisms [71–75] and seabirds [76,77], and metal contaminants carried by these microplastics may be released in the digestive tract of biota [64,78]. Thus, microplastic ingestion transfers metals into organisms and ecosystems. Adsorption of metals onto microplastics is controlled by the microplastic surface [65]. The smaller the particle size of microplastics, the higher the absorption rate of metals. Generally, interactions between microplastics and other pollutants in natural environments may be influenced by more complex ecological principles such as humic acid levels, compounds’ compositions, varying water temperature, salinity, and pH values [64,66]. For example, adsorption of metals to plastic pellets are metal specific with Cd, Co, Ni, and Pb increasing, whereas Cr decreases adsorption with increasing pH and decreasing salinity [79].

Studies have shown that microplastics from the environment contain diverse metals [66,80]. Aged microplastics enable higher adsorption of metals and certain microplastic polymers adsorb some of these metals more precisely [64]. Khalid et al. [64] showed desorption of metals was dependent on the pH of the external solution. Therefore, there exists plausible high ecotoxicological effects since the guts/digestive systems of organisms have low pH, which could enhance the desorption of toxic metals and thereby accumulate in their bodies [64]. Microplastics, thus, serve as a principal pathway and carrier of environmental metals, which are chiefly distributed in freshwater and marine ecosystems [80–82]. The study of Yuan et al. [66] showed that smaller microplastics showed increased adsorption levels for metals (higher toxicological risks) than that of larger microplastics. Furthermore, the combined effects of metals on polystyrene microplastics on the target organism Daphnia magna altered from antagonism to additive effect with increasing microplastics’ concentrations. Zhou et al. [83] reported that metals’ content on microplastics is related to the metal contamination in the environment, thus suggesting that microplastics be potential carriers for the transport of metals in the environment. Another study established strong correlations between the adsorbability of polypropylene and PVC to Pb and Mn and the metals concentrations in seawater [81].

3. Sources of Microplastics in Aquatic Environments

Microplastic pollution originates from manufactured products dumped or discharged into any aquatic environment either purposely or accidentally as well as being transported to this environment through runoffs, drainages, sewage systems, and by the action of winds, commonly referred to as Marine debris/litter [84–86]. Microplastics in the aquatic
Microplastics in the environment could be from primary and secondary sources [87]. Primary sources include unintentional or deliberate dumping of microbeads, microfibers, micro-pellets, and other products as identified by UNEP [88]. The products originate from industrial operations' waste or are derivatives from the erosion and plastic products including boards, tires, and wheels. Secondary microplastics occur through the breakdown by the action of biophysiochemical forces including biodegradation, heat, oxidation, UV light, and mechanical forces [89,90].

Microplastics in the environment can also be derived from land-based sources including the dumping of marine garbage from domestic/municipal use along shorelines, discharge of untreated sewage, agricultural practices, coastal tourism, and recreation, among others. Due to a 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 [20]. The buoyancy of most plastic materials (e.g., synthetic polymers) often facilitates their particles to float and then often be transported or washed ashore [91].

Ocean-based sources of microplastics include the dumping of discarded, 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 [92]. 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 [93].

Marine plastic pollution contributes to the loss of aesthetic values of the aquatic environment and disruption of fishing and tourism activities [94,95]. Plastic pollution also contributes to the disruption of cultural ties to natural resources’ availability and sustainable recreational activities [96]. 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 [97,98]. Yet, their accumulation in organisms and transport to the food chain level is such that they are detrimental to human health and a call for societal awareness and combat is needed.

4. Transfer, Accumulation, and Effects of Microplastics in the Food Chain

4.1. Effects of Microplastics on Aquatic Biota

Microplastics accumulate and are measured at widely varying concentrations in the marine environment [7]. Aquatic organisms and fish can assimilate and metabolize POPs adsorbed onto microplastics. These include PBDEs in tissues of the marine amphipod, Allorchestes compressa, and fish [23,99] as well as causing physical injuries on 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 listed as either threatened or near threatened have been affected by both entanglements by plastic rope and netting and ingestion of plastic fragments [2,100,101].

Microplastics can transfer POPs and other contaminants from biota into the marine food chain [102]. Microplastics can be mistaken for food by marine organisms such as macroinvertebrates (bivalves, mussels, shrimps, oysters), zooplankton, fishes, copepods, sea turtles, and birds, as well as whales [23,103]. In the food web, microplastics may pass through different trophic levels via the predator–prey feeding relationship [104]. This provides a route for the translocation of sorbed contaminants and additives from plastics into the tissues of aquatic organisms [105,106]. It is also likely that microplastic-consuming species in aquatic ecosystems ingest higher concentrations of chemical pollutants, such as POPs, than they would in aquatic ecosystems free from these micropollutants [19]. Microplastics provide substrates for inhabitation by marine organisms, as is 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 [107]. The small-particle nature of microplastics encourages their transportation over long distances, thereby enabling the dispersal to marine species such as invasive and pathogenic organisms [108,109]. 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 [21,32,73–75,110]. Some examples are listed for marine fish, zooplankton, and mussel species (Table 1).

4.1.1. Fish

Microplastics are present in the digestive organs of fish [74,110,111]. In Mondego estuary, Portugal, 157 microplastic fibers (96%) and fragments (4%) were extracted from the gastrointestinal tract of 120 fish [55]. 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 [112]. Furthermore, Pellini et al. [113] reported the dominance of polyethylene (PE), polypropylene (PP), and PVC, with 95% of benthic flatfish from the Adriatic Sea containing microplastics in their gastrointestinal tract. Similarly, Liu et al. [114] 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 can bioaccumulate toxic chemicals, which may result in liver toxicity and pathology [115]. Fish and fishery products are a source of animal protein in the developing world, containing several vital nutrients and omega 3 fatty acid and being low in saturated fat [116]. Potential human health implications exist from consumption of fish containing microplastics. Therefore, innovative and cost-effective approaches to mitigate microplastics from entering coastal waters is required.

4.1.2. Zooplankton

Planktonic organisms ingest microplastics from ambient water, mistaking them for prey [117,118]. ‘Mistaken prey’ may contain hazardous chemicals that, when ingested, may affect the ecophysiology of the organism [119]. This may include its feeding habit, cellular dysfunctions, molecular pathways, reproductive output, and respiratory functions. A study in Marseille Bay, France, evaluated phthalate concentrations in zooplankton samples and measured concentrations of di-n-butyl phthalate (DnBP) and diethylhexyl phthalate (DEHP) of 750 ng/g and 4000 ng/g, respectively [37]. Thus, chemical additives present in low-trophic-level organisms such as zooplankton may undergo trophic transfer through the entire food web.

4.1.3. Mussels

Mussels are consumed by humans globally [120]. Mussels are filter feeders that can ingest microplastics as well as pollutants in ambient water [121]. Mussels are, therefore, useful bioindicators for aquatic pollutants and microplastic pollution due to their sedentary nature and ability to bioaccumulate contaminants. For example, blue mussels exposed to polyethylene (HDPE) for 4 days (6 h daily) developed granulocytoma formations in their digestive glands and lysosomal membranes’ destabilization [122]. A study by Endo et al. [62] measured PCB concentrations of 11–1630 ng/g in blue mussels (Mytilus galloprovincialis) collected from the coastline of Japan. South African blue mussels also contain PCB concentrations of 14.48–21.37 ng/g [123]. Pyrene concentrations in the gills of blue mussels were higher than pyrene concentrations in microplastics in a study by Deudero et al. [118]. The increase in desorption of pyrene ingested by blue mussels in the study led to abnormalities and lethal effects on DNA and indicated neurotoxic effects. Continuous consumption of harvested contaminated blue mussels could pose potential human health implications through bioaccumulation.
Table 1. Microplastic impacts on marine organisms.

| Species Name | Effects | References |
|--------------|---------|------------|
| Blue mussel (M. edulis) | Decreased feeding activity | [123] |
| Blue mussel (M. edulis) | Formations of granulocytoma in digestive glands and lysosomal membranes’ destabilization | [121] |
| M. galloprovincialis | Ingestion of resin pellets | [62] |
| Zooplankton | Ingestion and accumulation of phthalic acid esters, organophosphate ester flame retardants, and plasticizers accumulated in zooplankton | [37] |
| Blue mussels (M. galloprovincialis) | Increased levels of absorption of PCBs led to toxic effects. The increase in desorption of pyrene ingested by the blue mussels led to abnormalities and lethal effects on DNA and indicated neurotoxic effects | [122] |
| Pelagic fishes and holothurians | Boops boops, a pelagic fish, ingested 70% of microplastics’ fibers. Ingestion of plastic pellets of holothurians via food web | [117] |
| Copepod (Calanus helgolandicus, C. cristatus, Euphausiapacifica) | Ingestion, reduced feeding, decreased reproduction rates, decrease in egg production | [118,124] |
| European flat oysters (Ostreaedulis) | Ingestion and abnormal respiration rates | [125] |
| Mussel | Cytotoxicity, decrease in phagocytic activity, and increase in lysozyme activity | [126] |
| Sea turtles (Chelonioidea) | Ingestion | [127] |
| Mussel, amphipods (Allorchestes compressa) | Granulocytomas and lysosomal membrane destabilization/vector for POP accumulation | [120,128–130] |
| Lugworm (Arenicola marina) | Ingestion may cause increased metabolic rates, reduced fecal casts’ formation, fitness effects | [99,125] |
| Brown shrimp (Crangon cragon) | Ingestion | [131] |
| Zebrafish (Danio rerio) | Found in fish tissues | [132] |
| Gooseneck barnacles (Lepas sp.) | Ingestion | [133] |
| Zooplankton | Microplastics entered embryos and larvae | [134] |
| Zooplankton (Centropages typicus, Daphnia magna) | Ingestion/decreased algal feeding/causes immobilization | [136,137] |
| Sea urchin | Ingestion | [138] |
| Demersal (cod, dab, flounder/pelagic fish (herring and mackerel), Oyster | Ingestion | [139] |
| Shore crab (Carcinus maenas) | Significantly increased mortality | [151] |
| Bivalves (M. edulis, Crassostrea gigas/Macoma bathica, M. trossulus) | Ingestion and accumulation in soft tissues | [128,141,142] |
| Marine fish (Pomatoschistus microps, Artemia nauplii, Danio rerio, Oryzias latipes) | Ingestion, liver inflammation, pathological oxidative stress, lipid accumulation in liver | [114,143–145] |
| Paracentrotus lividus | Growth deformities | [146] |
| Crassostrea virginica | Ingestion | [139,147] |
| Mytilus edulis | Translocation to the circulatory system | [148] |
| Nephrops norvegicus | Retention Accumulation | [149] |
| Semibalanus balanoides | Ingestion | [77] |
| Carcinus maenas | Retention | [148] |
| Mytis sp. | Ingestion | [150] |
| Arenicola marina | Reduced feeding habits and energy budget | [56] |
| Chironomus tepperi | Significantly increased mortality | [151] |
Table 1. Cont.

| Species Name                        | Effects                                                                 | References |
|-------------------------------------|-------------------------------------------------------------------------|------------|
| *Tripneustes gratilla*              | Significantly reduced body width                                        | [152]      |
| *Paracyclopina nana*                | Development significantly delayed for 0.05 µm                            | [153]      |
| *Palaemonetes pugio*                | Significantly increased mortality by larger particles (>75 µm)          | [154]      |
| *Mytilus galloprovincialis*         | Significantly increased number of dead hemocytes                         | [155]      |
| Seabirds (red-breasted mergansers  | Ingestion                                                               | [76]       |
| (Mergus serrator), Pacific loons   | Gastrointestinal tract and gills of fish. Cr and Fe were detected on    | [156]      |
| (Gavia pacifica), Swinhoe’s storm   | microplastics                                                            |            |
| petrels (Hydrobates monorhis),      | Ingestion and accumulation in soft tissues                              | [157]      |
| black-tailed gulls (Larus crassirostris), and ancient murrelets (Synthliboramphus antiquus) | Exposure (24 h and 7 days) to microplastics caused a short-lived increase in Superoxide dismutase (SOD) activity while nanoplastics’ exposure triggered an innate immune response | [158] |

4.2. Human Health Effects of Microplastics

The potential risks of microplastics to human health as emerging contaminants are in the early stages of investigation. There is evidence of obvious dietary exposure of humans to microplastics [6,159]. Ingestion, inhalation, and dermal contact are the reported routes of exposure for the human population [41]. 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 [35]. These organisms are involved in the food chain by transferring these toxic plastic particles up the trophic level. This includes fish that are eventually taken up by humans [160], 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 [41,161]. Microplastics in the food chain can lead to a decrease in nutritional diet value and exposure to pathogens [35]. Incidences of microplastic in drinking water abound, with various sources acclaimed to be responsible for its presence [162,163]. 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 Single-Use Plastic Reductions in Coastal Ecosystems

Microplastic pollution with its ensuing negative impacts on the environment has been regarded as a global problem with a great impact on marine biodiversity [2,19]. Although there are few policies aimed at reducing primary microplastics, except for bans of microbeads [164,165], there have been increasing interventions to reduce the use of single-use plastic bags in many jurisdictions (Table 2) to ensure they do not enter coastal waters [166–169]. This includes the ban of plastic bag sales, plastic bags’ charges, and taxes from plastic bags’ sellers [166]. 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 [166,170]. Some other African, Asian, and European countries have also developed plastic bag bans [171,172].

Table 2. Non-exhaustive examples of global plastic bag bans, adapted from [165,166].

| Country | Action Plan | Year | Policy | Aim | Enforcement | Tax, Levy, Fines | Impacts |
|---------|-------------|------|--------|-----|-------------|-----------------|---------|
| Africa  |             |      |        |     |             |                 |         |
| Nigeria | Ban         | 2019 | Interventions are lacking generally but the country is under pressure from experts to ban use of plastic bags since Kenya passed its policy. The Plastic Bags Prohibition Bill has been passed by the Federal House of Representatives but has not been approved by the Nigerian Senate or passed into Act (Law) | Plastic pollution mitigation | Not enforced | Defaulters are liable to pay fines of 500,000 Naira (N500,000 or USD 1290) or to imprisonment of up to 3 years or both penalties | The Bill is declining. Although it has not generated any interest, the impact would be enormous and eco-friendly. |
| Benin   | Partial Ban | 2018 | A ban on the production, importation, possession, and use of non-biodegradable plastics | Environmental Protection and sanitation | Poorly enforced | Defaulters are liable to a fine ranging from 5000–100,000 CFA francs (US $9–170) | In effect. Too early to assess impacts. |
| Kenya   | Ban         | 2017 | Implementation of a national ban on plastic bags including the importation, production, distribution, and use of single-use bags. The implementation of the ban of plastic bags on the distributors and producers of single-use bags | Environmental preservation, conservation, and protection. Solid waste management | Enforced | Violation may result in a 4-year prison sentence or a 40,000 KES (USD 376) fine | Although the law has been undermined by the activities of smugglers, there has been a reduction rate of about 100 million plastic bags used yearly |
| Ghana   | Tentative Ban, Ban | 2014 | There was an attempt to ban plastics but it failed to be implemented | Revenue generation for plastic waste management | Poorly enforced | Currently, no law banning plastic bags’ production, importation, or usage | The government believes plastic manufacturers play critical roles in the economy, hence, working effortlessly on managing plastics instead of banning them |
| Togo    | Ban         | 2011 | An intervention on the banning of the production, importation, possession, and commercial use of non-biodegradable plastics | Environmental Protection | - | Defaulters pay fines ranging from 5 million to 10 million FCAF (US $8517–17,035) or go to prison for terms between 2 months to 2 years | - |
Table 2. Cont.

| Country            | Action Plan | Year        | Policy                                                                 | Aim                              | Enforcement | Tax, Levy, Fines                  | Impacts                                                                 |
|--------------------|-------------|-------------|-----------------------------------------------------------------------|-----------------------------------|-------------|-------------------------------|-------------------------------------------------------------------------|
| Morocco            | Ban         | 2009        | Ban on manufacture, distribution, and importation of plastic bags     | Plastic bag pollution halt        | Poorly enforced | Violators pay fines ranging from $20,000 USD to over $100,000 USD | The government is ensuring that plastic bag alternatives are easily accessible. |
| Morocco            | Ban         | 2009 (Partial Ban), 2016 (Full Ban) | A national ban on non-biodegradable plastic bags prohibits the production, usage, importation, and sale of plastic bags. Visitors into the country are not allowed to bring plastic bags. | Plastic pollution mitigation | Poorly enforced | Fined, imprisoned, public confessions. Six months in jail for Smugglers and 1 year for company executives. License suspension of stores. Dispossession of plastic bags from plastics’ producers and a fine of 10 million Rwandan francs (USD 10) | Rwanda has seen an increase in tourism due to reduced plastic bags pollution resulting in an increase of about 177,000 new jobs. |
| South Africa       | Tax/ partial ban | 2003 | Prohibition of Plastic carrier bags and plastic flat bags less than 30 µm thick. Tax on thicker bags | Revenue generation. Removal and phasing out of harmful plastic products | Enforced | Levy, which increased from 12 cents to 25 cents in April 2020 | Between 2018/19 the revenue generated from bag levies increased by R59 million (USD 3 million) to R300 million (USD 17 million) |
| 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, 1 year in jail, cancellation of business license | Practice has been growing |
| 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 | An 80% drop in plastic bag consumption |
| India (Karnataka)  | Ban         | 2016        | Its law targeted the ban of different single-use plastic items, including plastic dinnerware. This policy puts pressure on manufacturers, consumers, and distributors. | 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. |
| Country | Action Plan | Year | Policy | Aim | Enforcement | Tax, Levy, Fines | Impacts |
|---------|-------------|------|--------|-----|-------------|-----------------|---------|
| 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 1593 USD, for 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. Additionally, 600,000 regulators have been sent to grocery stores around the country to ensure compliance. |
| Bangladesh | Ban | 2002 | The Bangladesh government banned the assembling, promoting, and utilization of polyethylene packs of less than 55 µm thickness. Jute fibers were used to replace polythene bags for packaging in 2010. | Environmental protection and plastic pollution mitigation | Non-enforced | Jail or a fine of TK50,000-10 lakh |Polythene has been continuously produced, traded, and utilized all 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. |
| Europe | | | | | | |
| France | Ban/Tax | 2017 | Supermarkets and retail stores are prohibited from distributing free plastic bags | Plastic waste reduction | - | Tax of €0.04 ($0.05 USD) per bag, rose to €0.07 ($0.09 USD) in 2019 | In effect. Too early to assess impacts. |
| Netherlands | Tax | 2016 | A tax is payable for plastic bags. Exemption from the levy applies to bags used for food or preventing food waste. | 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. | Ban resulted in a 40% reduction of plastic bag use |
| United Kingdom | Tax | 2015 | UK stores began charging 5 cent 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 | Plastic bag consumption has 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 |
| Bulgaria | Tax | 2012 | 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 |
| Country          | Action Plan | Year | Policy                                                                 | Aim                                                | Enforcement | Tax, Levy, Fines | Impacts                                                                 |
|-----------------|-------------|------|------------------------------------------------------------------------|----------------------------------------------------|-------------|-----------------|-------------------------------------------------------------------------|
| Ireland         | Tax         | 2002 | 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, in 2007, the levy increased to 22 Euro cents/bag. The levy was increased to 44 Euro cents in 2009. Discarded plastic bags amounted to 0.13% of litter pollution in 2015 as compared to an estimated 5% in 2001. |
| Denmark         | Tax         | 1994 | The legislation was passed that forces 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                | Reduction in the single-use plastic bags.                                   |
| Germany         | Tax         | 1991 | Legislation passed to ensure that retail stores providing plastic bags pay a tax or levy | Environmentally friendly                           | Enforced    | 5 or 10 Euro cents/bag.                                             | The reduction in the use of lightweight plastic bags.                      |
| Boston, MA      | Tax and Ban | 2018 | A dual approach of taxation and bans on single-use bags was implemented | Reduction of plastic waste                         | -           | A tax of 5 cents                                               | Over 350 million plastic bags that were utilized yearly were drastically reduced. |
| Canada          | Tax         | 2016 | Tax for all shopping bags                                              | To reduce plastic bag use                          | Non-enforced | Walmart Canada began charging customers a 5-cent fee                | -                                                                        |
| Seattle, WA     | Ban         | 2012 | Retail stores banned from releasing single-use bags. Grocery stores were permitted to use single-use bags that were composed of 40% recycled material | Reduction of plastic waste                         | -           | A tax of 5 cent per bag                                           | There has been a 78% reduction in plastic bag use.                         |
| United States of America | Tax | 2009 | Washington, D.C., was one of the first 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 D.C. locals reduced to 3.3 million bags per month compared to the initial 22.5 million bags per month. |
| Country          | Action Plan       | Year        | Policy                                                                 | Aim                                      | Enforcement | Tax, Levy, Fines | Impacts                                                                 |
|------------------|-------------------|-------------|------------------------------------------------------------------------|------------------------------------------|-------------|-----------------|--------------------------------------------------------------------------|
| San Francisco    | 2007, Amended in 2012 | Policy     | Policy implemented to use reusable bags by placing an additional 10-cent fee on single-use compostable or recycled paper bags that clients require at departure | Zero waste by 2020 and environmental stewardship | -           | No bag fee       | A decrease in plastic bag use by 72% was achieved since the policy was implemented in 2010. The amended ban anticipates further plastic bag reductions of between 70% to 90% |
| Oceania          |                   |             |                                                                         |                                           |             |                 |                                                                          |
| New Zealand      | 2019              | Ban         | Plastic shopping bags with a thickness <70 microns were banned in July 2019 after the first pronouncement on 18 December 2018. | Plastic pollution mitigation             | -           | 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             | -           | K50,000 fine on plastics. | The government promoted use of traditional and locally manufactured bilum bags. |
| Australia        | 2011              | Ban         | Banned plastic bags including 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     |                 | Ban eliminated 33% of plastic waste sent to landfills. It is estimated that 400 million bags were eliminated annually. An 80% decrease within 3 months, the two biggest supermarkets were banned from use of single-use plastics. |
| South America    |                   |             |                                                                         |                                           |             |                 |                                                                          |
| Chile            | 2017(2018)        | Ban         | Ban on businesses that keep distributing plastic bags, accompanied by government-coordinated beach cleanups, specifically during peak vacation times when most of the plastic waste is accumulated on the beach. | Plastic waste reduction                  | Enforced     | Fines equal to USD 300       | Some 80 municipalities have restricted plastic bag distribution, while some coastal and lakeside areas have banned plastic bags altogether. In late May 2018, major retailers were prohibited from using plastic bags while smaller retailers were given a grace of 2 years to stop plastic use. Within the period, only two bags for each customer were allowed. |
Table 2. Cont.

| Country   | Action Plan | Year | Policy                                                                 | Aim                              | Enforcement | Tax, Levy, Fines | Impacts                                           |
|-----------|-------------|------|------------------------------------------------------------------------|----------------------------------|-------------|------------------|---------------------------------------------------|
| Colombia  | Ban         | 2017 | 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.           |
| Brazil    | Ban         | 2015 | Ban on the distribution of plastic bags in supermarkets                | To encourage biodegradable bags   | Non-enforced | -                | Lack of enforcement prohibits seeing great positive impacts |
| Argentina | Ban         | 2012 | The province of Mendoza in Argentina joined Buenos Aires in a ban on plastic bags | To discourage non-biodegradable bags | -           | -                | Use of biodegradable bags and boosts recycling incentives |

In North America, Canada has imposed single-use plastic bag bans or levies in three provinces and several municipalities [165,173]. Similarly, the U.S. has implemented single-use plastic bag bans in four states [166], although many of these policies were reversed or postponed during the COVID-19 pandemic [18]. 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 until the moment, only Buenos Aires Province in Argentina has implemented a total plastic bag ban in markets [174]. India and China have the largest plastic discharge into the ocean [175]. They banned the manufacture of extremely light plastic bags. China established a bag fee in 2008, which decreased plastic bag use by 70% in supermarkets and reduced the use of 40 billion bags per year. However, this still did not prevent retailers from using and distributing plastic bags illegally [176]. 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 and is yet to be implemented [177]. A recent review by Schnurr et al. [165] found that the effectiveness of single-use plastic bag reduction interventions varied widely depending on policy, but reduction in use ranged from 33–96%. Although New Zealand and Bangladesh have policies for plastic bags, their impacts are yet to be seen [166]. Table 2 shows some countries and cities that have adopted different policies that have been implemented for curbing single-use plastic pollution.

While positive impacts of single-use plastic bag reduction policies are yet to be seen in some countries (Table 2), other countries are currently developing stringent policies and regulations to reduce other types of single-use plastics, which will indirectly reduce degradation into secondary microplastics. For example, on 12 May 2021 the Canadian federal government added manufactured single-use plastics items to the list of toxic substances under Schedule 1 of the Canadian Environmental Protection Act, 1999 [178]. By listing single-use plastics as toxic, the Canadian government can ban single-use plastic items. The ban includes six “harmful” single-use plastic items such as plastic checkout bags, straws, stir sticks, six-pack rings, cutlery, and food containers made from hard-to-recycle plastics [178]. These single-use plastic items are commonly found in plastics in the marine environment during beach clean-ups or citizen science monitoring surveys [164,179,180]. Additionally, EU countries have also been given directives towards single-use plastic and microplastic reduction [181]. Individual EU country participation is shown in Table 3.

Since single-use plastics are seen as indispensable commodities, industries keep manufacturing them and consumers continue to use them widely. It is important for governments to re-evaluate interventions to assess the effectiveness of policy interventions and it is also important to ensure sustainable alternatives are widely available to help reduce single-use plastic pollution [165].
Table 3. EU directives towards single-use plastic and microplastic reduction. Adapted from [181].

| EU Directives                        | Date                                                                 | Objective                                                                                     | EU Country Participation |
|--------------------------------------|----------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|--------------------------|
| Bio-based, biodegradable, and compostable plastics | First announced 11 December 2019, published action plan on 11 March 2020 | The EU will address the sourcing, labelling, and use of bio-based plastics, and the use of biodegradable and compostable plastics | Denmark                  |
| Global action on plastics            | Adopted December 2020, UNEA5.2 will take place from 28 February to 4 March 2022 | The EU is paving way for a global agreement on plastics, to support the global shift towards a circular economy | Germany                  |
| Microplastics                        | The first and second stakeholder meetings held September and November 2021, respectively. | The EU aims to address the growing volume of microplastics in the environment                  | Netherlands, Austria, Belgium, Sweden, Luxembourg |
| Plastic bags                         | Amendment to the Packaging and Packaging Waste Directive (94/62/EC) | EU rules on plastic bags to address the unsustainable consumption and use of lightweight plastic carrier bags | Ireland, Denmark, France |
| Plastic packaging                    | Entry into force on 31 December 1994. 30 September 2020–6 January 2021 was an open public consultation on the review of requirements for packaging and other measures to prevent packaging waste | EU rules on packaging and packaging waste cover all materials, including plastics           | Netherlands              |
| Plastic waste shipments              | Entry into force on 1 January 2021                                   | EU rules on importing and exporting plastic waste                                           | Poland                   |
| Single-use plastics (SUP)            | 2 July 2019, Commission adopted the Implementing Decision 2021/1752 by 1 October 2021 | EU rules on SUPs to fight against marine litter and plastic pollution                         | Bulgaria                 |

5.1. Microbead Ban Interventions

Microbeads have progressively been manufactured (to substitute natural exfoliating materials, including pumice, oatmeal, and walnut husks) [108]. They are recently used in cleaning products, printer toners, plastic blasting, textile printing, automotive molding, and medical applications [182]. According to UNEP [32], cosmetics products may contain higher concentrations of microbeads than the plastic container itself. Although wastewater treatment plants can effectively trap 90–99% of microplastics or microbeads, once they are released into the environment, they may be extremely difficult to remove from aquatic ecosystems [164,183].

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 [165,166] (Table 4). The Canadian government classified these microbeads as toxic substances under the Canadian Environmental Protection Act [164,165]. The increase in the use of such microbead-containing cosmetics in the 20th century gave rise to the national bans on the sale and use of microbeads. Only a few countries have taken this step. For example, Canada has implemented a ban on single-use toiletries and cosmetics containing microbeads from stores [184]. The province of Ontario passed legislation banning the manufacture of microbeads in 2015 [185]. The classification of microbeads as a toxin was initiated to develop microbead regulations and prohibit the manufacture, import, and sale of certain exfoliating personal care products [165,186].
Table 4. Non-exhaustive examples of global microbead policy interventions adapted from [165,166].

| 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 1 January 2018 and to ban manufacturing of these cosmetics beginning on 1 July 2017. although the bans were delayed by 1 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. | In 2015, 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, and Illinois, among others. |
| Austria, Belgium, Sweden, Netherlands, Luxembourg (Multi-national) | 2015 | These countries issued a joint statement requesting a ban on 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 a commitment to stop using microplastics and microbeads in their products. |
| Canada (National) | 2016 (2018–2019) | National ban on 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, was 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 commenced in June 2017. |

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 [165,187]. The ban on the use of microbeads in rinse-off cosmetics and personal care products took effect in the United Kingdom with the Environmental Protection (Beads) Regulations (England) in 2017 [188]. The scope of this legislation in the United Kingdom far exceeds the “Bead-Free Water Act” passed by the US government in 2015 [189]. 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 [190]. 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 detailed China’s microbead ban. China’s legislation banned the
production of new cosmetics containing microbeads in 31 December 2020 [191]. The sale of existing cosmetics containing microbeads will be banned before 31 December 2022.

5.2. Critiques in Plastic and Microbead Ban Interventions and the Way Forward

Plastic bags and microbead interventions are significant enactments of policies and legislation [165,192,193]. The absence of statutory law formulations, as well as being weak and poorly enforced with inadequate compliance in most developing countries, contributes to the continuous discharge of plastics and microplastics into the coastal waters. As there exist environmental regulations to monitor different environmental pollutions, 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 [37,112]. These explain that government alone might not necessarily achieve the goal of eradicating microplastics in 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, such as plastic dumping, pose risks to these ecosystems may improve public dynamics and communities’ involvement in marine ecosystems’ protection from microplastics’ pollution [167]. There exists an idea by policy makers that the socio-cultural impact of microplastic pollution could be a central reason to solve the challenges of microplastic pollution [194]. Therefore, in-depth knowledge of the environmental fate and potential adverse effects of microplastics in aquatic environments is needed. With the increase in 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 is that 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 [195].

Threats from this emerging toxic pollutant to the ecosystem and biodiversity are a dire need for continuous research. The amount of PPE waste generated due to COVID-19 undeniably threatens the existing waste management systems and infrastructures; there is evidence of increased environmental and human health risks [15,17,18,196]. 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. [167] 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 [167]. Alpizar et al. [20] suggested an impact pathway framework to trace the flow of plastics’ socio-ecological system. The pathway was aimed at identifying the role of specific policy instruments in achieving behavioral changes to reduce marine plastic waste into the sea.

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 (Figure 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 [197]. 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 and roles and eventually support and partake in the mitigation process. We, therefore, propose a co-management model for active participation of microplastics’ mitigation from coastal waters. The proposed co-management model offers lasting solutions for microplastic pollution. Specific roles of stakeholders for feasible microplastics’ mitigation are highlighted in the model (Figure 1).

![Figure 1. Proposed co-management model for microplastics’ mitigation.](image-url)

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 regarding their absorptions, periods of exposures, and tropic-level transfers 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 provides significant governance challenges given the related risks and ubiquity of microplastics in the marine environment [198]. 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 [199,200]. It has, thus, progressively become a transboundary issue that needs absolute priority for mitigation considerations and attention from different stakeholders [198].

6.1. Governance Approaches to Microplastics’ Pollution

Several governance strategies are apt to curb plastic use and avert marine environmental pollution [198]. 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 [201]. Efforts to tackle microplastics globally have been restricted to weak and fragmented acts [202]. Addressing the microplastics’ problem is crucial for accomplishing and actualizing sustainable ocean governance and the 2030 Sustainable Development Goals (SDGs) [203]). 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 ubiquitous nature of microplastics thus places them 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 [198].

Continuous international cooperation is needed to unravel this transboundary issue [198]. Nevertheless, the global collaboration required remains fragmented and reflects the extremely decentralized nature of the international system [200]. 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 [204]. 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 [205]. 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 [206]. 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 was designed for 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 [198]. However, as we are in 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 [207].
Discrepancies between the directives and actions of government agencies deter collaboration and communication essential for implementing wide-ranging management plans [207]. 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 [207]. It is, therefore, imperative for collaborations from environmental stakeholders and scientists to address environmental pollution challenges for a better policy harmonization [208]. Lessons are 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 [209]. Although the role of science in international governance needs strengthening through institutionalized platforms for knowledge exchange [210], 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 [198]. Scientists, government, and governance researchers will need to utilize a structured collaborative management model, as proposed in this review (Figure 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 see plastic debris and microplastics as global concerns in need of a global response [211]. 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 United Nations Sustainable Development Goals (UN SDGs) to regional and national levels, with support from scientific research relevant to local communities, can form the basis for successful plastic debris management [21,173,211]. 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 can be meted out, especially for the sustenance of biodiversity [2,212].

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 [213]. The 3Rs are what Lohr et al. [212] 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 [214]. 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 [215]. 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 the 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, depolymerizing to produce poly(g-butyrolactone); virgin-
like plastics can be quantitatively depolymerized through heating the bulk product into the original g-butyrolactone [216,217]. The present consequence of depolymerizable plastics is that they are limited in mechanical and thermal properties, which are also reflected in their usage [216].

The quest for (marine) environment-friendly plastics gave rise to green plastics (green chemistry) [41]. 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 [218]. 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 [41]. Additionally, 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 polyactic acid plastics, but this is not easy to synthesize, and the active site spatial confinement in the zeolite micropores mainly determines its selectivity [219].

Consequently, the durability quality of plastics is the basis for their use in some applications; 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].

Moreover, to prevent plastic debris, prevention, legislation, and market-based instruments 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), taxes and charges, and container deposit schemes [20,212,220]. 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. Additionally, Lohr et al. [212] pointed out that the 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. Furthermore, Nwafor and Walker [221] suggested that redrafting Bills including other proactive measures, such as proper planning, coordination, implementation, and enforcement, before final enactment into law could transition plastic pollution to a reduced rate. This could ensure the effectiveness of the few documented legislative bans on curbing plastic pollution in some developing countries and Africa, specifically. Notwithstanding that, there is a need for co-management and collaborations among the governments, research institutions, and industries in redesigning materials and rethinking their usage and disposal techniques, to reduce microplastics’ waste from pellets, synthetic textiles, and tires. This includes understanding the compositions of plastic materials and 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, policy makers, 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 [222]. 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 [223]. Organizing seminars and conferences to educate the public on the need to care for the environment and how to properly care for it 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 [224,225]. 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 [226]. 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 [222,227]. 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 into the marine environment to help ensure coastal sustainability.

7. Conclusions and Recommendations

Microplastics are globally abundant, ubiquitous, and persistent. Coupled with increasing levels of aquatic chemical pollutants that can be readily sorbed and concentrated into microplastics, which can be consumed indiscriminately by aquatic organisms, they pose 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 the 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 the use and consumption of plastics and to provide incentives for plastic pollution prevention and waste reduction (Figure 2).

![Figure 2. Future directions for microplastics mitigation.](image-url)

The following areas are recommended for future research:

- How do chemical pollutants that leach from microplastics once ingested become adsorbed into the tissues of aquatic organisms?
- More studies required 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.
- More studies on fragmentations of microplastics into nanoparticles, as microplastics have greater size dependent effects on aquatic organisms.
- Continued re-evaluation of community and government strategies to measure effectiveness for plastic waste reduction.
• Long-term monitoring to further characterize microplastics and establish their interactions with persistent organic pollutants is required.
• More studies on the fragmentation of microplastics into nanoplastics are required, as nanoplastics could have more detrimental size-dependent effects on aquatic organisms.
• Continued re-assessment of community and government strategies for plastic waste reduction is required.

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References
1. Zhang, S.; Wang, J.; Liu, X.; Qu, F.; Wang, X.; Wang, X.; Li, Y.; Sun, Y. Microplastics in the environment: A review of analytical methods, distribution, and biological effects. TrAC Trends Anal. Chem. 2019, 111, 62–72. [CrossRef]
2. Gall, S.C.; Thompson, R.C. The impact of debris on marine life. Mar. Pollut. Bull. 2015, 92, 170–179. [CrossRef] [PubMed]
3. Goldstein, M.C.; Rosenberg, M.; Cheng, L. Increased oceanic microplastic debris enhances oviposition in an endemic pelagic insect. Biol. Lett. 2012, 8, 817–820. [CrossRef]
4. Lebreton, L.; Auta, A. Future scenarios of global plastic waste generation and disposal. Palgrave Commun. 2019, 5, 1–11. [CrossRef]
5. Agenda, I. The New Plastics Economy Rethinking the Future of Plastics. Available online: https://ellenmacarthurfoundation.org/the-new-plastics-economy-rethinking-the-future-of-plastics (accessed on 16 September 2021).
6. Pelley, J. Plastic Contamination of the Environment: Sources, Fate, Effects, and Solutions; American Chemical Society: Washington DC, USA, 2018; pp. 2–21.
7. Andrady, A.L. Microplastics in the marine environment. Mar. Pollut. Bull. 2011, 62, 1596–1605. [CrossRef] [PubMed]
8. Fok, L.; Cheung, P.K. Hong Kong at the Pearl River Estuary: A hotspot of microplastic pollution. Mar. Pollut. Bull. 2015, 99, 112–118. [CrossRef] [PubMed]
9. Hurley, R.; Woodward, J.; Rothwell, J.J. Microplastic contamination of river beds significantly reduced by catchment-wide flooding. Nat. Geosci. 2018, 11, 251–257. [CrossRef]
10. Nel, H.A.; Smith, G.H.S.; Harmer, R.; Sykes, R.; Schneidewind, U.; Lynch, I.; Krause, S. Citizen science reveals microplastic hotspots within tidal estuaries and the remote Scilly Islands, United Kingdom. Mar. Pollut. Bull. 2020, 161, 111776. [CrossRef]
11. Simon-Sánchez, L.; Grelaud, M.; García-Orellana, J.; Ziveri, P. River Deltas as hotspots of microplastic accumulation: The case study of the Ebro River (NW Mediterranean). Sci. Total Environ. 2019, 687, 1186–1196. [CrossRef]
12. Alimi, O.S.; Fadare, O.O.; Okoffo, E.D. Microplastics in African ecosystems: Current knowledge, abundance, associated contaminants, techniques, and research needs. Sci. Total Environ. 2020, 755, 142422. [CrossRef]
13. Oni, B.A.; Ayeni, A.O.; Agboola, O.; Oguntade, T.; Obanla, O. Comparing microplastics contaminants in (dry and raining) seasons for Ox-Bow Lake in Yenagoa, Nigeria. Ecotoxicol. Environ. Saf. 2020, 198, 110656. [CrossRef]
14. Naidoo, T.; Glassom, D. Sea-surface microplastic concentrations along the coastal shelf of KwaZulu–Natal, South Africa. Mar. Pollut. Bull. 2019, 149, 110514. [CrossRef] [PubMed]
15. Prata, J.C.; Silva, A.L.; Walker, T.R.; Duarte, A.C.; Rocha-Santos, T. COVID-19 pandemic repercussions on the use and management of plastics. Environ. Sci. Technol. 2020, 54, 7760–7765. [CrossRef] [PubMed]
16. Borrelle, S.B.; Ringma, J.; Law, K.L.; Monnahan, C.C.; Lebreton, L.; McGivern, A.; Murphy, E.; Jambeck, J.; Leonard, G.H.; Hilleary, M.A.; et al. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science 2020, 369, 1515–1518. [CrossRef] [PubMed]
17. Silva, A.L.P.; Prata, J.C.; Walker, T.R.; Duarte, A.C.; Ouyang, W.; Barcelò, D.; Rocha-Santos, T. Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations. Chem. Eng. J. 2021, 405, 126683. [CrossRef] [PubMed]
18. Silva, A.L.P.; Prata, J.C.; Walker, T.R.; Campos, D.; Duarte, A.C.; Soares, A.M.; Barcelò, D.; Rocha-Santos, T. Rethinking and optimising plastic waste management under COVID-19 pandemic: Policy solutions based on redesign and reduction of single-use plastics and personal protective equipment. Sci. Total Environ. 2020, 742, 140565. [CrossRef] [PubMed]
19. Yu, Q.; Hu, X.; Yang, B.; Zhang, G.; Wang, J.; Ling, W. Distribution, abundance and risks of microplastics in the environment. Chemosphere 2020, 249, 126659. [CrossRef] [PubMed]
20. Alpizar, F.; Carlsson, F.; Lanza, G.; Carney, B.; Daniels, R.C.; Jaime, M.; Ho, T.; Nie, T.; Salazar, B.; Tibesigwa, B.; et al. A framework for selecting and designing policies to reduce marine plastic pollution in developing countries. Environ. Sci. Pollut. Res. 2020, 109, 25–35. [CrossRef]
21. Kershaw, P.J.; Rochman, C.M. Sources, Fate and Effects of Microplastics In the Marine Environment: Part 2 of A Global Assessment; UNEP/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection: Rome, Italy, 2016.
22. Wilcox, C.; Mallos, N.J.; Leonard, G.H.; Rodriguez, A.; Hardesty, B.D. Using expert elicitation to estimate the impacts of plastic pollution on marine wildlife. Mar. Policy 2016, 65, 107–114. [CrossRef]
23. Auta, H.S.; Emenike, C.U.; Fauziah, S.H. Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions. Environ. Int. 2017, 102, 165–176. [CrossRef] [PubMed]
24. Wang, J.; Tan, Z.; Peng, J.; Qiu, Q.; Li, M. The behaviors of microplastics in the marine environment. Mar. Environ. Res. 2016, 133, 7–17. [CrossRef] [PubMed]
25. Rodriguez, F. Plastic; Chemical Compound. 2019. Available online: http://www.britannica.com/science/plastic (accessed on 3 April 2020).
26. Hidalgo-Ruz, V.; Gutow, L.; Thompson, R.C.; Thiel, M. Microplastics in the marine environment: A review of the methods used for identification and quantification. Environ. Sci. Technol. 2012, 46, 3060–3075. [CrossRef] [PubMed]
27. Lyons, B.P.; Cowie, W.J.; Maes, T.; Le Quesne, W.J.F. Marine plastic litter in the ROPME Sea Area: Current knowledge and recommendations. Ecotoxicol. Environ. Saf. 2020, 187, 109839. [CrossRef] [PubMed]
28. Pham, C.K.; Ramirez-Llodra, E.; Alt, C.H.S.; Amaro, T.; Bergmann, M.; Canals, M.; Company, J.B.; Davies, J.; Duineveld, G.; Galgani, F.; et al. Marine litter distribution and density in European seas, from the shelves to deep basins. PLoS ONE 2014, 9, e95839. [CrossRef] [PubMed]
29. Oberbeckmann, S.; Labrenz, M. Marine Microbial Assemblages on Microplastics: Diversity, Adaptation, and Role in Degradation. Annu. Rev. Mar. Sci. 2019, 12, [CrossRef] [PubMed]
30. Napper, I.E.; Bakir, A.; Rowland, S.J.; Thompson, R.C. Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. Mar. Pollut. Bull. 2015, 99, 178–185. [CrossRef]
31. Crawford, C.B.; Quinn, B. Microplastic Pollution; Elsevier Inc: Amsterdam, The Netherlands, 2017.
32. UNEP. Plastic in Cosmetics: Are We Polluting the Environment Throughout Personal Care? Plastic Ingredients That Contribute to Marine Microplastic Litter. 2015. Available online: http://web.unep.org/ourplanet/september-2015/unep-publications/plasticscosmetics-are-we-polluting-environment-through-our-personal care (accessed on 11 June 2020).
33. Tubau, X.; Canals, M.; Lastras, G.; Rayo, X.; Rivera, J.; Amblas, D. Marine litter on the floor of deep submarine canyons of the Northwestern Mediterranean Sea: The role of hydrodynamic processes. Prog. Oceanogr. 2015, 134, 379–403. [CrossRef]
34. Constant, M.; Kerherve, P.; Sola, J.; Sanchez-Vidal, A.; Canals, M.; Heussner, M. Floating Microplastics in the Northwestern Mediterranean Sea: Temporal and Spatial Heterogeneities. In Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea; Cucca, M.; Di Pace, E.; Errico, M.E.; Gentile, G.; Montarsolo, A.; Mossotti, R., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 9–15. [CrossRef]
35. Padrervand, M.; Lichtousse, E.; Robert, D.; Wang, C. Removal of microplastics from the environment. A review. Environ. Chem. Lett. 2020, 18, 807–828. [CrossRef]
36. Suhrhouf, T.J.; Scholz-Bottcher, B.M. Qualitative impact of salinity, UV radiation and turbulence on leaching of organic plastic additives from four common plastics—a lab experiment. Mar. Pollut. Bull. 2016, 102, 84–94. [CrossRef] [PubMed]
37. Schmidt, N.; Castro-Jiménez, J.; Fauveille, V.; Sempéré, R. Zooplankton and Plastic Additives—Insights into the Chemical Pollution of the Low-Trophic Level of the Mediterranean Marine Food Web. In Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea; Cucca, M.; Di Pace, E.; Errico, M.E.; Gentile, G.; Montarsolo, A.; Mossotti, R., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 121–129. [CrossRef]
38. Net, S.; Sempéré, R.; Delmont, A.; Paluselli, A.; Ouddane, B. Occurrence, fate, behavior and ecotoxicological state of phthalates in different environmental matrices. Environ. Sci. Technol. 2015, 49, 4019–4035. [CrossRef]
39. Paluselli, A.; Aminot, Y.; Galgani, F.; Net, S.; Sempéré, R. Occurrence of phthalate acid esters (PAEs) in the northwestern Mediterranean Sea and the Rhone River. Prog. Oceanogr. 2018, 163, 221–231. [CrossRef]
40. Melzer, D.; Rice, N.E.; Lewis, C.; Henley, W.E.; Galloway, T.S. Association of urinary bisphenol a concentration with heart disease: Evidence from NHANES 2003/06. PLoS ONE 2010, 5, e8673. [CrossRef] [PubMed]
41. Thompson, R.C.; Moore, C.J.; Vom Saal, F.S.; Swan, S.H. Plastics, the environment and human health: Current consensus and future trends. Philos. Trans. R. Soc. B Biol. Sci. 2009, 1, 1–14. [CrossRef]
42. Xu, S.; Zhang, L.; Lin, Y.; Li, R.; Zhang, F. Layered double hydroxides used as flame retardant for engineering plastic acrylonitrile-butadiene-styrene (ABS). J. Phys. Chem. Solids 2012, 73, 1514–1517. [CrossRef]

43. Webster, L.; Russell, M.; Walshaw, P.; Phillips, L.A.; Hussey, I.; Packer, G.; Dalgarno, E.J.; Moffat, C.F. An assessment of persistent organic pollutants inScottishcostal and offshore marine environments. J. Environ. Monit. 2011, 13, 1288–1307. [CrossRef] [PubMed]

44. Castro-Jiménez, J.; Berrojalbiz, N.; Pizarro, M.; Dachs, J. Organophosphate ester (OPE) flame retardants and plasticizers in the open Mediterranean and Black Seas atmosphere. Environ. Sci. Technol. 2014, 48, 3203–3209. [CrossRef]

45. Pan, B.C.; Wan, S.L.; Zhang, S.J.; Guo, Q.; Xu, Z.; Lv, L.; Zhang, W. Recyclable polymer-based nano-hydrous manganese dioxide for highly efficient Ti(IV) removal from water. Sci. China Chem. 2014, 57, 763–771. [CrossRef]

46. Karbalaei, S.; Hanachi, P.; Rafiee, G.; Seifori, P.; Walker, T.R. Toxicity of polystyrene microplastics on juvenile Oncorhynchus mykiss (rainbow trout) after individual and combined exposure with chlorpyrifos. J. Hazard. Mater. 2021, 403, 123980. [CrossRef] [PubMed]

47. Kelly, B.C.; Ikonomou, M.G.; Blair, J.D.; Morin, A.E.; Gobas, F.A. Food web–specific biomagnification of persistent organic pollutants. Science 2007, 317, 236–239. [CrossRef]

48. Van, A.; Rochman, C.M.; Flores, E.M.; Hill, K.L.; Vargas, E.; Vargas, S.A.; Hoh, E. Persistent organic pollutants in small craft harbour debris found on beaches in San Diego, California. Chemosphere 2012, 86, 258–263. [CrossRef] [PubMed]

49. Vijgen, J.; Abhilash, P.C.; Li, Y.F.; Lal, R.; Forter, M.; Torres, J.; Singh, N.; Yunus, M.; Tian, C.; Schäffer, A.; et al. Hexachlorocyclohexane (HCH) as new Stockholm Convention POPs—a global perspective on the management of Lindane and its waste isomers. Environ. Sci. Pollut. Res. 2011, 18, 52–62. [CrossRef] [PubMed]

50. Davis, E.; Walker, T.R.; Adams, M.; Willis, R. Characterization of polycyclic aromatic hydrocarbons (PAHs) in small craft harbour (SCH) sediments in Nova Scotia, Canada. Mar. Pollut. Bull. 2018, 137, 285–294. [CrossRef] [PubMed]

51. Davis, E.; Walker, T.R.; Adams, M.; Willis, R.; Norris, G.A.; Henry, R.C. Source apportionment of polycyclic aromatic hydrocarbons (PAHs) in small craft harbor (SCH) surficial sediments in Nova Scotia, Canada. Sci. Total Environ. 2019, 691, 528–537. [CrossRef] [PubMed]

52. Perelo, L.W. Review; in situ and bioremediation of organic pollutants in aquatic sediments. J. Hazard. Mater. 2010, 177, 81–89. [CrossRef]

53. Davis, E.; Walker, T.R.; Adams, M.; Willis, R. Characterization of polycyclic aromatic hydrocarbons (PAHs) in small craft harbour (SCH) sediments in Nova Scotia, Canada. Mar. Pollut. Bull. 2018, 137, 285–294. [CrossRef] [PubMed]

54. Peters, C.A.; Bratton, S.P. Urbanization is a major influence on microplastic ingestion by sunfish in the Brazos River Basin, Central Texas, USA. Environ. Pollut. 2016, 210, 380–387. [CrossRef] [PubMed]

55. Bessa, F.; Barria, P.; Neto, J.M.; Frias, J.P.; Otero, V.; Sobral, P.; Marques, J.C. Microplastics in Juvenile Commercial Fish from an Estuarine Environment. In Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea; Cocca, M., Di Pace, E., Errico, M.E., Gentile, G., Montarsolo, A., Mossotti, R., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 131–135. [CrossRef]

56. Wright, S.L.; Rowe, D.; Thompson, R.C.; Galloway, T.S. Microplastic ingestion decreases energy reserves in marine worms. Curr. Biol. 2013, 23, R1031–R1033. [CrossRef]

57. Hirai, H.; Takada, H.; Ogata, Y.; Yamashita, R.; Mizukawa, K.; Saha, M.; Kwan, C.; Moore, C.; Gray, H.; Laursen, D.; et al. Organic micropollutants in marine plastics debris from the open ocean and remote and urban beaches. Mar. Pollut. Bull. 2011, 62, 1683–1692. [CrossRef] [PubMed]

58. Rochman, C.M.; Manzano, C.; Hentschel, B.T.; Simonich, S.L.M.; Hoh, E. Polystyrene plastic: A source and sink for polycyclic aromatic hydrocarbons in the marine environment. Environ. Sci. Technol. 2013, 47, 13976–13984. [CrossRef] [PubMed]

59. Lee, H.; Shim, W.J.; Kwon, J.-H. Sorption capacity of plastic debris for hydrophobic organic chemicals. Sci. Total Environ. 2014, 470, 1545–1552. [CrossRef] [PubMed]

60. Mato, Y.; Iseobe, T.; Takada, H.; Kanehiro, H.; Ohtake, C.; Kaminuma, T. Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. Environ. Sci. Technol. 2001, 35, 318–324. [CrossRef]

61. Velzeboer, I.; Kwdijik, C.J.A.F.; Koelmans, A.A. Strong sorption of PCBs to nanoplastics, microplastics, carbon nanotubes, and fullerences. Environ. Sci. Technol. 2014, 48, 4869–4876. [CrossRef]

62. Endo, S.; Takizawa, R.; Okuda, K.; Takada, H.; Chiba, K.; Kanehiro, H.; Ogi, H.; Yamashita, R.; Date, T. Concentration of polychlorinated biphenyls (PCBs) in beached resin pellets: Variability among individual particles and regional differences. Mar. Pollut. Bull. 2005, 50, 1103–1114. [CrossRef]

63. Karapanagioti, H.K.; Endo, S.; Ogata, Y.; Takada, H. Diffuse pollution by persistent organic pollutants as measured in plastic pellets sampled from various beaches in Greece. Mar. Pollut. Bull. 2011, 62, 312–317. [CrossRef]

64. Khalid, N.; Aqeel, M.; Noman, A.; Khan, S.M.; Akhter, N. Interactions and effects of microplastics with heavy metals in aquatic and terrestrial environments. Environ. Pollut. 2021, 260, 118104. [CrossRef]

65. Naqash, N.; Prakash, S.; Kapoor, D.; Singh, R. Interaction of freshwater microplastics with biota and heavy metals: A review. Environ. Chem. Lett. 2020, 18, 1–12. [CrossRef]

66. Yuan, W.; Zhou, Y.; Chen, Y.; Liu, X.; Wang, J. Toxicological effects of microplastics and heavy metals on the Daphnia magna. Sci. Total Environ. 2020, 746, 141254. [CrossRef]
67. Botterell, Z.L.R.; Beaumont, N.; Dorrington, T.; Steinke, M.; Thompson, R.C.; Lindeque, P.K. Bioavailability and effects of microplastics on marine zooplankton: A review. Environ. Pollut. 2019, 245, 98–110. [CrossRef] [PubMed]

68. Qayoom, U.; Bhat, S.U.; Ahmad, I.; Kumar, A. Assessment of potential risks of heavy metals from wastewater treatment plants of Srinagar city, Kashmir. Int. J. Environ. Sci. Technol. 2021, 1–20. [CrossRef]

69. Brennecke, D.; Duarte, B.; Paiva, F.; Cadador, I.; Canning-Clode, J. Microplastics as vector for heavy metal contamination from the marine environment. Estuar. Coast. Shelf Sci. 2016, 178, 189–195. [CrossRef]

70. Maity, S.; Biswas, C.; Banerjee, S.; Guchhait, R.; Adhikari, M.; Chatterjee, A.; Pramanick, K. Interaction of plastic particles with heavy metals and the resulting toxicological impacts: A review. Environ. Sci. Pollut. Res. 2021, 28, 1–17. [CrossRef] [PubMed]

71. Sleight, V.A.; Bakir, A.; Thompson, R.C.; Henry, T.B. Assessment of microplastic sorbed contaminant bioavailability through analysis of biomarker gene expression in larval zebrafish. Mar. Pollut. Bull. 2017, 116, 291–297. [CrossRef] [PubMed]

72. Gao, F.; Li, J.; Sun, C.; Zhang, L.; Jiang, F.; Cao, W.; Zheng, L. Study on the capability and characteristics of heavy metals enriched on microplastics in marine environment. Mar. Pollut. Bull. 2019, 144, 61–67. [CrossRef] [PubMed]

73. Dobaradaran, S.; Schmidt, T.C.; Nabipour, I.; Khajeahmadi, N.; Tajbaksh, S.; Saeedi, R.; Mohammad, M.J.; Keshikar, M.; Khorsand, M.; Ghasemi, F.F. Characterization of plastic debris and association of metals with microplastics in coastline sediment along the Persian Gulf. Waste Manag. 2018, 78, 649–658. [CrossRef] [PubMed]

74. Zhou, Y.; Liu, X.; Wang, J. Characterization of microplastics and the association of heavy metals with microplastics in subterranean soil of central China. Sci. Total Environ. 2019, 694, 133798. [CrossRef]

75. García-Rivera, S.; Lizaso, J.L.S.; Millán, J.M.B. Composition, spatial distribution and sources of macro-marine litter on the Gulf of Alicante seafloor (Spanish Mediterranean). Mar. Pollut. Bull. 2017, 121, 249–259. [CrossRef]

76. Galgani, F.; Hanke, G.; Werner, S.; Oosterbaan, L.; Nilsson, P.; Fleet, D.; Kinsey, S.; Thompson, R.C.; Van Franeker, J.; Vlachogianni, T.; et al. MSFD GES technical subgroup on marine litter. In Monitoring Guidance for Marine Litter in European Seas; Publications Office of the European Union: Luxembourg City, Luxembourg, 2013; p. 120.

77. Macfadyen, G.; Huntington, T.; Cappell, R. Abandoned, Lost or Otherwise Discarded Fishing Gear; United Nations Environment Programme, Food and Agriculture Organization of the United Nations: Rome, Italy, 2009.

78. Li, W.C.; Tse, H.F.; Fok, L. Plastic waste in the marine environment: A review of sources, occurrence and effects. Sci. Total Environ. 2016, 566–567, 333–349. [CrossRef]

79. Gasperi, J.; Wright, S.L.; Dris, R.; Collard, F.; Mandin, C.; Guerreauche, M.; Langlois, V.; Kelly, F.J.; Tassin, B. Microplastics in air: Are we breathing it in? Curr. Opin. Environ. Sci. Health 2018, 1, 1–5. [CrossRef]

80. Rillig, M.C.; Ingraffia, R.; De Souza Machado, A.A. Microplastic incorporation into soil in agroecosystems. Front. Plant Sci. 2017, 8, 1805. [CrossRef]

81. Zhang, K.; Su, J.; Xiong, X.; Wu, X.; Wu, C.; Liu, J. Microplastic pollution of lakeshore sediments from remote lakes in Tibet plateau, China. Environ. Pollut. 2016, 219, 450–455. [CrossRef] [PubMed]

82. Wace, N. Ocean litter stranded on Australian coasts. In State of the Marine Environment Report for Australia: Technical Annex 2—Pollution; Zarm, L.P., Sutton, D., Eds.; Great Barrier Reef Marine Park Authority: Townsville, QLD, Australia, 1995.

83. Detecting Japan Tsunami Marine Debris at Sea: A Synthesis of Efforts and Lessons Learned NOAA Marine Debris Program. Available online: https://marinedebris.noaa.gov/sites/default/files/JTMD_Detection_Report.pdf (accessed on 16 September 2021).
94. Wright, S.L.; Thompson, R.C.; Galloway, T.S. The physical impacts of microplastics on marine organisms: A review. *Environ. Pollut.* 2013, 178, 483–492. [CrossRef]

95. Adam, I. Tourists’ perception of beach litter and willingness to participate in beach clean-up. *Mar. Pollut. Bull.* 2021, 170, 112591. [CrossRef]

96. Office of Response and Restoration. Looking Deeper at the Social Science behind Marine Pollution. 2019. Available online: https://response.restoration.noaa.gov/about/looking-deeper-social-science-behind-marine-pollution (accessed on 30 December 2019).

97. Van der Meulen, M.D.; DeVriese, L.; Lee, J.; Maes, T.; Van Dalsen, J.A.; Huvet, A.; Soudant, P.; Robbens, J.; Vethaak, A.D. Socioeconomic impact of microplastics in the 2 Seas and France Manche Region: An initial risk assessment. MICRO Interreg Project IVa. *Meded. ILVO* 2014, 177, 3.

98. Beaumont, N.J.; Janssen, C.R. Microplastics in the aquatic and terrestrial environment: Sources (with a specific focus on personal care products), fate and effects. *Environ. Sci. Eur.* 2013, 28, 1–25. [CrossRef] [PubMed]

99. De Trender, C.A.; Devriese, L.I.; Haegeman, A.; Maes, S.; Ruttkin, T.; Dawyndt, P. Bacterial community profiling of plastic litter in the Belgian part of the North Sea. *Environ. Sci. Technol.* 2015, 49, 9629–9638. [CrossRef] [PubMed]

100. Wright, S.L.; Thompson, R.C.; Galloway, T.S. The physical impacts of microplastics on marine organisms: A review. *Environ. Pollut.* 2013, 178, 483–492. [CrossRef] [PubMed]

101. Lehner, R.; Petri-Fink, A.; Rothen-Rutishauser, B. Nanoplastic Impact on Human Health—A 3D Intestinal Model to Study the Interaction with Nanoplastic Particles. In Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea; Cocca, M., Di Pace, E., Errico, M.E., Gentile, G., Montarsolo, A., Mossotti, R., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 167–170. [CrossRef]

102. Pellini, G.; Gomiero, A.; Fortibuoni, T.; Fabi, G.; Grati, F.; Tassetti, A.N.; Polidori, P.; Vega, C.F.; Scarcella, G. Plastic Soles: Microplastic Litter in the Gastrointestinal Tract of Solea solea from the Adriatic Sea. In Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea; Cocca, M., Di Pace, E., Errico, M.E., Gentile, G., Montarsolo, A., Mossotti, R., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 159–165. [CrossRef]

103. Van der Hal, N.; Yeruham, E.; Angel, D.L. Dynamics in Microplastic Ingestion During the Past Six Decades in Herbivorous Fish on the Mediterranean Sea; Cocca, M., Di Pace, E., Errico, M.E., Gentile, G., Montarsolo, A., Mossotti, R., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 137–149. [CrossRef]

104. Farrell, P.; Nelson, K. Trophic level transfer of microplastic: *Mytilus edulis* (L.) to *Carcinusmaenas* (L.). *Mar. Pollut. Bull.* 2015, 92, 99–104. [CrossRef]

105. Gutow, L., Klages, M., Eds.; Marine Anthropogenic Litter; Springer: New York, NY, USA, 2015; pp. 59–61. [CrossRef]

106. Browne, M.A.; Niven, S.J.; Galloway, T.S.; Rowland, S.J.; Thompson, R.C. Microplastic moves pollutants and additives to worms, reducing functions linked to health and biodiversity. *Curr. Biol.* 2013, 23, 2388–2392. [CrossRef]

107. Ryan, P.G. A Brief History of Marine Litter Research; Bergmann, M., Gutow, L., Klages, M., Eds.; Marine Anthropogenic Litter; Springer: New York, NY, USA, 2015; pp. 1–2. [CrossRef]

108. Liu, Y.-P.; Li, J.-G.; Zhao, Y.-F.; Wen, S.; Huang, F.-F.; Wu, Y.-N. Polybrominated diphenyl ethers (PBDEs) and indicator polychlorinated biphenyls (PCBs) in marine fish from four areas of China. *Chemosphere* 2011, 83, 168–174. [CrossRef] [PubMed]

109. Rochman, C.M.; Hoh, E.; Kurobe, T.; Teh, S.J. Ingested plastic transfers hazardous chemicals to fish and induces hepatic stress. *Sci. Rep.* 2013, 3, 3263. [CrossRef]

110. Pal, J.; Shukla, B.N.; Maurya, A.K.; Verma, H.O.; Pandey, G.; Amitha, A. A review on role of fish in human nutrition with special emphasis to essential fatty acid. *Int. J. Fish. Aquat. Stud.* 2016, 8, 427–430. [CrossRef]

111. Van Cauwenbergh, L.; Janssen, C.R. Microplastics in bivalves cultured for human consumption. *Environ. Pollut.* 2014, 193, 65–70. [CrossRef] [PubMed]
144. Ferreira, P.; Fonte, E.; Soares, M.E.; Carvalho, F.; Guilhermino, L. Effects of multi stressors on juveniles of the marine fish Pomatoschistus microps: Gold nanoparticles, microplastics and temperature. *Aquat. Toxicol.* 2016, 170, 89–103. [CrossRef]

145. Batel, A.; Linti, F.; Scherer, M.; Braunbeck, T. The transfer of benzo [a] pyrene from microplastics to Artemia nauplii and further to zebrafish via trophic food web experiment- CYP1A induction and visual tracking of persistent organic pollutants. *Environ. Toxicol. Chem.* 2016, 35, 1656–1666. [CrossRef] [PubMed]

146. Lu, Y.; Zhang, Y.; Deng, Y.; Jiang, W.; Zhao, Y.; Geng, J.; Ding, L.; Ren, H. Uptake and accumulation of polystyrene microplastics in zebra fish (Danio rerio) and toxic effects in liver. *Environ. Sci. Technol.* 2016, 50, 4054–4060. [CrossRef] [PubMed]

147. Ward, J.E.; Zhao, S.; Holohan, B.A.; Mladinich, K.M.; Griffin, T.W.; Wozniak, J.; Shumway, S.E. Selective ingestion and egestion of plastic particles by the blue mussel (*Mytilus edulis*) and eastern oyster (*Crassostrea virginica*): Implications for using bivalves as bioindicators of microplastic pollution. *Environ. Sci. Technol.* 2019, 53, 8776–8784. [CrossRef]

148. Ward, J.E.; Kach, D.J. Marine aggregates facilitate ingestion of nanoparticles by suspension-feeding bivalves. *Mar. Environ. Res.* 2009, 68, 137–142. [CrossRef]

149. Murray, F.; Cowie, P.R. Plastic contamination in the decapod crustacean Nephrops norvegicus. *Limnées*, 1758. *Mar. Pollut. Bull.* 2011, 62, 1207–1217. [CrossRef]

150. Thompson, R.C.; Olsen, Y.; Mitchell, R.P.; Davis, A.; Rowland, S.J.; John, A.W.G.; McGonigle, D.; Russell, A.E. Lost at sea: Where is all the plastic? *Science* 2004, 304, 838. [CrossRef]

151. Setälä, O.; Fleming-Lehtinen, V.; Lehtiniemi, M. Ingestion and transfer of microplastics in the planktonic food web. *Environ. Pollut.* 2014, 185, 77–83. [CrossRef]

152. Ziajahromi, S.; Kumar, A.; Neale, P.A.; Leusch, F.D.L. Environmentally relevant concentrations of polyethylene microplastics negatively impact the survival, growth and emergence of sediment-dwelling invertebrates. *Environ. Pollut.* 2018, 236, 425–431. [CrossRef] [PubMed]

153. Kaposi, K.L.; Mos, B.; Kelaher, B.P.; Dworjanyn, S.A. Ingestion of microplastics has limited impact on a marine larva. *Environ. Sci. Technol.* 2014, 48, 1638. [CrossRef]

154. Jeong, C.-B.; Kang, H.-M.; Lee, M.-C.; Kim, D.-H.; Han, J.; Hwang, D.-S.; Souissi, S.; Lee, S.-J.; Shin, K.-H.; Park, H.G.; et al. Adverse effects of microplastics and oxidative stress-induced MAPK/Nrf2 pathway-mediated defense mechanisms in the marine copepod *Paracyclopina nana*. *Sci. Rep.* 2017, 7, 1–11. [CrossRef] [PubMed]

155. Gray, A.D.; Weinstein, J.E. Size and shape-dependent effects of microplastic particles on adult daggar blade grass shrimp (*Palaemonetes pugio*). *Environ. Toxicol. Chem.* 2017, 36, 3074–3080. [CrossRef]

156. Jaafar, N.; Azfaraliraff, A.; Musa, S.M.; Mohamed, M.; Yusoff, A.H.; Lazim, A.M. Occurrence, distribution and characteristics of microplastics in gastrointestinal tract and gills of commercial marine fish from Malaysia. *Sci. Total Environ.* 2021, 799, 149547. [CrossRef]

157. Sparks, C. Microplastics in Mussel s along the Coast of Cape Town, South Africa. *Bull. Environ. Contam. Toxicol.* 2020, 104, 423–431. [CrossRef]

158. Cole, M.; Liddle, C.; Consolandi, G.; Drago, C.; Hird, C.; Lindeque, P.K.; Galloway, T.S. Microplastics, microfibres and nanoplastics cause variable sub-lethal responses in mussels (*Mytilus spp*). *Mar. Pollut. Bull.* 2020, 160, 111552. [CrossRef]

159. Paul-Pont, I.; Fabioux, C.; et al. Exposure of marine mussels *Mytilus spp.* to polystyrene microplastics: Toxicity and influence on fluoranthene bioaccumulation. *Environ. Pollut.* 2016, 216, 724–737. [CrossRef]

160. Wright, S.L.; Kelly, F.J. Plastic and Human Health: A Micro Issue? *Environ. Sci. Technol.* 2017, 51, 6634–6647. [CrossRef] [PubMed]

161. Deng, P.; Xu, Z.; Kuang, Y. Electrochemical determination of bisphenol-A in plastic bottled drinking water and canned beverages using a molecularly imprinted chitosan–graphene composite film modified electrode. *Food Chem.* 2014, 157, 490–497. [CrossRef] [PubMed]

162. Comanită, E.; Hlihor, R.M.; Gavriulescu, C.; Ghinea, M. Occurrence of plastic waste in the environment: Ecological and health risks. *Environ. Eng. Manag. J.* 2016, 15, 675–685. [CrossRef]

163. Asmonthi, G.; Almroth, B.C. Effects of Microplastics on Organisms and Impacts on the Environment: Balancing the Known and Unknown; Report Submitted to the Department of Biological and Environmental Sciences; University of Gothenburg: Gothenburg, Sweden, 2019; p. 5.

164. Pettipas, S.; Bernier, M.; Walker, T.R. A Canadian policy framework to mitigate plastic marine pollution. *Mar. Policy* 2016, 68, 117–122. [CrossRef]

165. Schnurr, R.E.J.; Alboiu, V.; Chaudhary, M.; Corbett, R.A.; Quanz, M.E.; Sankar, K.; Srain, H.S.; Thavarajah, V.; Xanthos, D.; Walker, T.R. Reducing marine pollution from single-use plastics (SUPs): A review. *Mar. Pollut. Bull.* 2018, 137, 157–171. [CrossRef] [PubMed]

166. Xanthos, D.; Walker, T.R. International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): A review. *Mar. Pollut. Bull.* 2017, 118, 17–26. [CrossRef] [PubMed]

167. Adam, I.; Walker, T.R.; Bezerra, J.C.; Clayton, A. Policies to reduce single-use plastic marine pollution in West Africa. *Mar. Policy* 2020, 116, 103928. [CrossRef]

168. Clayton, C.A.; Walker, T.R.; Bezerra, J.C.; Adam, I. Policy responses to reduce single-use plastic marine pollution in the Caribbean. *Mar. Pollut. Bull.* 2020, 162, 111833. [CrossRef]
169. Bezerra, J.C.; Walker, T.R.; Clayton, C.A.; Adam, I. Single-use plastic bag policies in the Southern African development community. *Environ. Chall.* 2021, 3, 100029. [CrossRef]

170. Dikgang, J.; Leiman, A.; Visser, M. Analysis of the plastic-bag levy in South Africa. *Resour. Conserv. Recycl.* 2012, 66, 59–65. [CrossRef]

171. Agence France-Press. Kenya Bans Plastic Bags. The Independent. 2011. Available online: http://www.independent.co.uk/environment/kenya-bans-plastic-bags2179928.html (accessed on 4 January 2020).

172. Zero Waste Scotland. Carrier Bag Charge Scotland. 2014. Available online: http://carrierbagchargescotland.org.uk/ (accessed on 4 January 2020).

173. Walker, T.R. (Micro) plastics and the UN sustainable development goals. *Curr. Opin. Green Sustain. Chem.* 2021, 30, 100497. [CrossRef]

174. Poortinga, W.; Whitmarsh, L.; Suffolk, C. The introduction of a single-use carrier bag charge in Wales: Attitude change and behavioural spillover effects. *J. Environ. Psychol.* 2013, 36, 240–247. [CrossRef]

175. Paya, C. An Integrated System of Waste Management in a Developing Country Case Study: Santiago de Cali. Master’s Thesis, University of Waterloo, Waterloo, Colombia, 2016.

176. Jambek, J.R.; Geyer, R.; Wilcox, C.; Siegler, T.R.; Perryman, M.; Andrady, A.; Narayan, R.; Law, K.L. Plastic waste inputs from land into the ocean. *Science* 2015, 347, 768–771. [CrossRef] [PubMed]

177. Block, B. China Reports 66-Percent Drop in Plastic Bag Use. 2013. Available online: http://www.worldwatch.org/node/6167 (accessed on 4 January 2020).

178. Walker, T.R. Plastic industry plan to sue the Canadian federal government for listing plastic as toxic may increase plastic marine pollution. *Mar. Pollut. Bull.* 2021, 169, 112583. [CrossRef]

179. Walker, T.R.; Grant, J.; Archambault, M.-C. Accumulation of marine debris on an intertidal beach in an urban park (Halifax Harbour, Nova Scotia). *Water Res. J.* 2006, 41, 256–262. [CrossRef]

180. Ambrose, K.K.; Box, C.; Boxall, J.; Brooks, A.; Eriksen, M.; Fabres, J.; Fylakis, G.; Walker, T.R. Spatial trends and drivers of marine debris accumulation on shorelines in South Eleuthera, The Bahamas using citizen science. *Mar. Pollut. Bull.* 2019, 142, 145–154. [CrossRef] [PubMed]

181. EU. Turning the Tide on Single-Use Plastics. 2021. Available online: https://euroalert.net/publication/738/turning-the-tide-on-single-use-plastics (accessed on 27 July 2021).

182. Clean Up Australia. Report on Actions to Reduce Circulation of Single-Use Plastic Bags around the World. 2015. Available online: https://www.cleanup.org.au/single-use-plasticbags (accessed on 27 July 2021).

183. Rochman, C.M.; Kross, S.M.; Armstrong, J.B.; Bogan, M.T.; Darling, E.S.; Green, S.J.; Smyth, A.R.; Veríssimo, D. Scientific evidence supports a ban on microbeads. *Environ. Sci. Technol.* 2015, 49, 10759–10761. [CrossRef] [PubMed]

184. Rochman, C.M.; Tahir, A.; Williams, S.L.; Baxa, D.V.; Lam, R.; Miller, J.T.; Teh, F.-C.; Werorliang, S.; Teh, S.J. Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. *Sci. Rep.* 2015, 5, 1–10. [CrossRef] [PubMed]

185. Walker, T.R.; Xanthos, D. A call for Canada to move toward zero plastic waste by reducing and recycling single-use plastics. *Resour. Conserv. Recycl.* 2018, 133, 99–100. [CrossRef]

186. Bill 75, Microbead Elimination and Monitoring Act, 2015. Available online: https://www.ola.org/en/legislative-business/bills/parliament-41/session-1/bill-75 (accessed on 27 July 2021).

187. CEPA (Canadian Environmental Protection Act). SOR/2016-150. 17 June 2016. Available online: http://www.gazette.gc.ca/rp/pr/p2/2016/2016-06-29/html/sordors150-eng.php (accessed on 30 August 2021).

188. The Economist. What Are Microbeads and Why Would Canada Ban Them? 2015. Available online: http://www.economist.com/blogs/economist-explains/2015/08/economistexplains-0 (accessed on 30 August 2021).

189. United Kingdom Department for Environment Food and Rural Affairs. Microbead Ban Announced to Protect Sealife. Department for Environment, Food and Rural Affairs. 2016. Available online: https://www.gov.uk/government/news/microbead-ban-announced-to-protectsealife (accessed on 27 July 2021).

190. United States Congress. H.R.1321-Microbead-Free Waters Act of 2015; U.S. Government Publishing Office: Washington, USA, 2015.

191. Hunt, C.F.; Lin, W.H.; Voulvoulis, N. Evaluating alternatives to plastic microbeads in cosmetics focusing on European policies. Has the issue been handled effectively? *Mar. Pollut. Bull.* 2021, 162, 111883. [CrossRef] [PubMed]

192. WHO–World Health Organization. Microplastics in Drinking-Water. 2019. Available online: https://www.who.int/water_sanitation_health/publications/microplastics-in-drinking-water/en/ (accessed on 1 February 2020).

193. Anagnosti, L.; Varvaresou, A.; Pavlou, P.; Protopapa, E.; Carayanni, V. Worldwide actions against plastic pollution from microbeads and microplastics in cosmetics focusing on European policies. Has the issue been handled effectively? *Mar. Pollut. Bull.* 2021, 162, 111883. [CrossRef] [PubMed]

194. Vince, J.; Hardesty, B.D. Plastic pollution challenges in marine and coastal environments: From local to global governance. *Restor. Ecol.* 2017, 25, 123–128. [CrossRef]

195. Jeyasanta, K.I.; Sathish, N.; Patterson, J.; Edward, J.P. Macro- meso and microplastic debris in the beaches of Tuticorin district, Southeast coast of India. *Mar. Pollut. Bull.* 2020, 154, 111055. [CrossRef] [PubMed]

196. Prata, J.C.; Silva, A.L.P.; Duarte, A.C.; Rocha-Santos, T. Disposable over Reusable Face Masks: Public Safety or Environmental Disaster? *Environments* 2021, 8, 31. [CrossRef]
197. Karim, M.E.; Sanjee, S.A.; Mahmud, S.; Shaha, M.; Moniruzzaman, M.; Das, K.C. Microplastics pollution in Bangladesh: Current scenario and future research perspective. *Chem. Ecol.* 2019, 36, 83–99. [CrossRef]

198. DasGupta, R.; Shaw, R. Changing perspectives of mangrove management in India–An analytical overview. *Ocean Coast. Manag.* 2013, 80, 107–118. [CrossRef]

199. Stoll, T.; Stoett, P.; Vince, J.; Hardesty, B.D. Governance and Measures for the Prevention of Marine Debris. In *Handbook of Microplastics in the Environment*; Springer: Cham, Switzerland, 2020; pp. 1–23. [CrossRef]

200. Thompson, R.C. *Microplastics in the Marine Environment: Sources, Consequences and Solutions*; Bergmann, M., Gutow, L., Klages, M., Eds.; Marine anthropogenic litter; Springer International Publishing: Cham, Switzerland, 2015; pp. 185–200. [CrossRef]

201. Vince, J.; Hardesty, B.D. Governance solutions to the tragedy of the commons that marine plastics have become. *Front. Mar. Sci.* 2018, 5, 214. [CrossRef]

202. Villarrubia-Gomez, P.; Cornell, S.E.; Fabres, J. Marine plastic pollution as a planetary boundary threat—The drifting piece in the sustainability puzzle, *Mar. Policy* 2018, 96, 213–220. [CrossRef]

203. Mika, K.; Leitner, L.; Gold, M.; Horowitz, C.; Herzog, M. Stemming the Tide of Plastic Marine Litter: A Global Action Agenda; Open Access Publications from the University of California, UCLA School of Law: Los Angeles, CA, US, 2013.

204. United Nations. Sustainable Development Goals–Knowledge Platform, United Nations. 2020. Available online: https://sustainabledevelopment.un.org/?menu
d1300 (accessed on 10 May 2020).

205. Nielsen, T.D.; Holmberg, K.; Stripple, J. Need a bag? A review of public policies on plastic carrier bags–where, how and to what effect? *Waste Manag.* 2019, 87, 428–440. [CrossRef] [PubMed]

206. Simon, N.; Knoblauch, D.; Mederake, L.; McGlade, K.; Schulte, M.L.; Masali, S. *No More Plastics in the Ocean–Gaps in Global Plastic Governance and Options for a Legally Binding Agreement to Eliminate Marine Plastic Pollution*; Adelphi: Berlin, Germany, 2018.

207. Stoett, P. *Global Ecopolitics: Crisis, Governance, and Justice*, 2nd ed.; University of Toronto Press: Toronto, ON, Canada, 2019.

208. Wigginton, N.S. Synthesizing more sustainable plastics. *Science* 2017, 358, 453–460. [CrossRef]

209. Koppelman, B.; Day, N.; Davison, N.; Elliott, T.; Wilsdon, J. New Frontiers in Science Diplomacy: Navigating the Changing Balance of Power. *Lond. R. Soc.* 2010, 1, 10.

210. Ferraro, G.; Failler, P. Governing plastic pollution in the oceans: Institutional challenges and areas for action. *Environ. Sci. Policy* 2020, 112, 453–460. [CrossRef]

211. Cvitanovic, C.; Hobday, A.J. Building optimism at the environmental science-policy-practice interface through the study of bright spots. *Nat. Commun.* 2018, 9, 3466. [CrossRef]

212. Lühr, A.; Savelli, H.; Beunen, R.; Kalz, M.; Ragas, A.; Van Belleghem, F. Solutions for global marine litter pollution. *Curr. Opin. Environ. Sustain.* 2017, 28, 90–99. [CrossRef]

213. Schuyler, Q.A.; Wilcox, C.; Townsend, K.A.; Wedemeyer-Strombel, K.R.; Balazs, G.; van Sebille, E.; Hardesty, B.D. Risk analysis reveals global hotspots for marine debris ingestion by sea turtles. *Glob. Chang. Biol.* 2016, 22, 567–576. [CrossRef] [PubMed]

214. Callister, W.D., Jr.; Rethwisch, D.G. *Fundamentals of Materials Science and Engineering*, 3rd ed.; John Wiley and Sons: New York, NJ, USA, 2008.

215. Singh, N.; Hui, D.; Singh, R.; Ahuja, I.P.S.; Fere, L.; Fraternali, F. Recycling of plastic solid waste: A state of art review and future applications. *Compos. Part B Eng.* 2017, 115, 409–422. [CrossRef]

216. Hong, M.; Chen, E.Y. Chemically Recyclable Polymers: A Circular Economy Approach to Sustainability. *Green Chem.* 2017, 19, 3692–3706. [CrossRef]

217. Sardón, H.; Dove, A.P. Plastics recycling with a difference: A novel plastic with useful properties can easily be recycled again and again. *Science* 2018, 360, 380–381. [CrossRef]

218. Garcia, J.M.; Jones, G.O.; Virwani, K.; McCloskey, B.D.; Boday, D.J.; terHuurne, G.M.; Horn, H.W.; Coady, D.J.; Bintaleb, A.M.; Alabdulrahman, A.M.; et al. Recyclable, strong thermosets and organogels via paraformaldehyde condensation with diamines. *Science* 2014, 344, 732–735. [CrossRef] [PubMed]

219. Fahrenkamp-Uppenbrink, J. Routes to greener plastics. *Science* 2017, 358, 882–884.

220. Wiggins, N.S. Synthesizing more sustainable plastics. *Science* 2015, 349, 78. [CrossRef]

221. Nwafor, N.; Walker, T.R. Plastic Bags Prohibition Bill: A developing story of crass legalism aiming to reduce plastic marine pollution in Nigeria. *Mar. Policy* 2020, 120, 104160. [CrossRef]

222. Jakovcevic, A.; Steg, L.; Mazzeo, N.; Caballero, R.; Franco, P.; Putrino, N.; Favara, J. Charges for plastic bags: Motivational and behavioral effects. *J. Environ. Psychol.* 2014, 40, 372–380. [CrossRef]

223. Kuo, F.-J.; Huang, H.-W. Strategy for mitigation of marine debris: Analysis of sources and composition of marine debris in northern Taiwan. *Mar. Pollut. Bull.* 2014, 83, 70–78. [CrossRef] [PubMed]

224. Derraik, J.G.B. The pollution of the marine environment by plastic debris: A review. *Mar. Pollut. Bull.* 2002, 44, 842–852. [CrossRef]

225. Jones, M.M. Fishing debris in the Australian marine environment. *Mar. Pollut. Bull.* 1995, 30, 25–33. [CrossRef]
226. Walker, T.R.; Adebambo, O.; Feijoo, M.C.D.A.; Elhaimer, E.; Hossain, T.; Edwards, S.J.; Morrison, C.E.; Romo, J.; Sharma, N.; Taylor, S.; et al. Environmental effects of marine transportation. In *World Seas: An Environmental Evaluation*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 505–530.

227. Goodman, A.J.; McIntyre, J.; Smith, A.; Fulton, L.; Walker, T.R.; Brown, C.J. Retrieval of abandoned, lost, and discarded fishing gear in Southwest Nova Scotia, Canada: Preliminary environmental and economic impacts to the commercial lobster industry. *Mar. Pollut. Bull.* 2021, 171, 112766. [CrossRef]