Policies and Responses of Microplastics

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Contributor: Davi R. Munhoz , Paula Harkes , Nicolas Beriot , Joana Larreta , Oihane C. Basurko

Although (micro)plastic contamination is a worldwide concern, most scientific literature only restates that issue rather than presenting strategies to cope with it. The knowledge are assembled on policies and responses to tackle plastic pollution, including peer-reviewed scientific literature, gray literature and relevant reports to provide: (1) a timeline of policies directly or indirectly addressing microplastics; (2) the most up-to-date upstream responses to prevent microplastics pollution, such as circular economy, behavioral change, development of bio-based polymers and market-based instruments as well as source-specific strategies, focusing on the clothing industry, tire and road wear particles, antifouling paints and recreational activities; (3) a set of downstream responses tackling microplastics, such as waste to energy, degradation, water treatment plants and litter clean-up strategies; and examples of (4) multifaceted responses focused on both mitigating and preventing microplastics pollution, e.g., approaches implemented in fisheries and aquaculture facilities.

microplastic contamination policymaking prevention mitigation

1. Policies Tackling (Micro)Plastic Contamination

1.1. Overview

Seven decades after the invention of synthetic plastic, several conventions started to tackle plastic pollution. Although most regulations initially addressed plastic pollution in general, they directly influenced the mid-2000s to 2020 regulations targeting microplastics.

1.2. Pioneer Conventions

Pioneer legislative efforts in the 1970s [1][2][3][4] started to regulate both land and sea-based pollution, i.e., the direct or indirect introduction of substance or energy into the environment by humans that would lead to deleterious effects to living resources, ecosystems, amenities and human health [5][6]. In the following decade, the United Nations (UN) conventions [7][8] tackling the marine pollution and transboundary movement of hazardous materials gained force, leading to the elaboration of agendas [7], compulsoriness annexes [9] and refund–deposit systems [10]. Grounded under these legal efforts, the 1990s have boosted measures to cope with anthropogenic waste. The Helsinki Convention “HELCOM” (1992) classified harmful substances as “any substance, which, if introduced to the sea, is liable to cause pollution” [11][12]. Moreover, the UN “Global Programme of Action for the protection of the marine environment from land-based activities” [13] came up with action plans to tackle both land- and sea-based pollution. Although plastics were not explicitly mentioned in any of the aforementioned policies and yet were not included in the program on persistent organic pollutants [13], some well-known conventions and action plans were amended to tackle plastic pollution. For instance, the Barcelona Convention [14][15], the Northwest Pacific Action Plan [16], the OSPAR convention [4], and the amended Basel Convention, which explicitly mentioned microplastics [15][16].

1.3. Policies and Initiatives Tackling Plastics

Scaffolded on the conventions tackling contaminants, policies directly targeting plastics have begun to emerge. Europe continued to establish several policies [15][17][18][19], and the European Marine Framework Directive (2008/56/EC) (MSFD) emphatically addressed plastic pollution [15][20][21]. The United Nations (UN) embraced the concerns and encouraged stakeholder involvement [22], financed regional seas to combat marine litter, identified potential market-based instruments [10] and provided guidelines for worldwide efforts [9]. Those initiatives reverberated, and 69 world plastic organizations committed to dealing with the financial loss from plastic waste [23]. Furthermore, Taiwan encouraged deposit-refund policies [16]; China announced the Prevention and Control of Waste Plastic Processing and Utilization [24]; and management strategies were proposed to reduce littering in the Antarctic [25].

Between 2013 and 2020, the policies and initiatives tackling plastic contamination or even banning plastics boomed worldwide. The following ones are worth highlighting since they function as a scaffold for the current policies in place: Regional plans [12][15][26]; national, regional and collective agreements [27][28]; MARPOL 73/78 annex amendment [1]; UN resolutions encouraging stakeholder involvement and monitoring programs [25]; national laws [24]; Directives (EU)2015/720 [29] [30], (EU)2018/851 [31], (EU)2019/904 [32]; taxation reforms, e.g., Portuguese Law n° 82-D/2014 [33]; restriction on the imports of plastic waste [34]; and Single-use plastic bans [35][36]. These efforts led to the European Strategy for Plastic in a Circular Economy to transform plastics design, production and recycling [37], as well as the scientific urge to recommend marine plastic pollution as a planetary boundary threat [38]. Plastic bans in India [39] and China [10] and restrictions in Taiwan [16] led the way in Asia. Nevertheless, challenges concerning inefficient enforcement and bureaucracy emerged [36]. Considering the current movement toward a carbon-neutral Europe by 2025 [4] and an environmentally-friendly future worldwide, more top-down policies are yet to come. For example, the Hainan provincial government in China announced the ban on non-degradable plastic products after 2025 [36]; the Ocean Plastics Charter was approved by eight countries to enhance the plastic circular economy by 2030 [30]; and the UNEP proposed to decrease marine plastic litter to zero by 2050 through the G20 Osaka Blue Ocean Vision [40].

1.4. Policies and Initiatives Directly Tackling Microplastics

Almost 35 years after the first initiatives tackling land- and sea-based pollution, the term microplastics was coined by Thompson and colleagues [41]. Due to the groundwork on policymaking carried out to tackle macroplastics, the inclusion of microplastics in policies took merely four years, when they were first addressed in the MSFD (2008) [15][20][21]. That triggered a cascade effect. In 2012, the United Nations Conference on Sustainable Development, held in Brazil (Rio + 20), emphatically addressed microplastics as an emergent environmental issue [42][43]. The reasoning of microplastics as harmful substances still resonates in the last updated version of the "Oceans and the Law of the Sea" [40].

In the following years, microplastics were banned in wash-off cosmetic products in the US [44], the Netherlands [45], France, Taiwan, South Korea, Sweden [30] and the UK [46]. The International Coral Reef Initiative and the Secretariat of the Antarctic Treaty endorsed the reduction of plastic microbeads [47][48]; the European Chemicals Agency (ECHA) followed the same line of thought to tackle microbeads [49]; and Canada classified microplastics as toxins in personal care products [9][50]. However, only personal care products were tackled, and microbeads and other microplastics in abrasive materials, such as plastic blasting and automotive molding, were disregarded [9]. Furthermore, HELCOM proposed a regional action plan to tackle microplastics, including recommendations on legal instruments to act upon it, encouraging microplastic-free formulas and replacing microplastics in personal care products [12]. Additionally, monitoring programs [36] and UN resolutions 1/6 and 2/11 on marine plastic litter and microplastics started to consider microplastic contamination as one of the six key emerging environmental issues [51][52]. The United Nations Member States committed to supporting the implementation of the Sustainable Development Goal (SDG) 14 [53], including a reduction of microplastic contamination. However, the other SDGs lack indicators related to microplastics [54].

Further policymaking targeting (micro)plastics is foreseen for the following years, since the United Nations formulated a comprehensive plan to target microplastics worldwide under the 2030 Agenda for Sustainable Development [55]. It highlights the need for setting up action plans, technologies and strategies to prevent and reduce microplastic pollution, promote stakeholder engagement and assess environmental and socioeconomic costs, feasibility and effectiveness of the abovementioned, amongst others [55]. A key question remains: Will there be enough enforcement for top-down and bottom-up policies and initiatives coming up in the following years?

2. Upstream Responses to Prevent Microplastic Pollution

2.1. Circular Economy

A circular economy is an intersection between environmental sustainability, economic prosperity and social equality [56][57]. The transition toward a circular economy requires a fundamental shift in the design, production, consumption and end-of-life management of plastic products. That is, using raw materials more efficiently and reducing waste production to a minimum. Circular economy stands out as a long-term solution to cope with plastic pollution [1][57][58][59]. Although this shift demands investments in infrastructure and behavioral changes, substantial economic benefits are foreseen since about 95% of the plastic packaging value is lost after its first use [43]. Circular economy is pivotal for the reduction of mainly secondary microplastics in the environment [39], since the eco-design and the use of alternative materials for SUP items can enhance products' shelf-life, mechanical properties and increase recyclability [39][60].

Life Cycle Assessments (LCA) are often used to evaluate products' environmental impacts, to encourage eco-design [61] and thus to foment a circular economy [62]. Currently, the marILCA impact assessment methodology includes an impact category for marine litter and may serve as a reference to also tackle microplastics, by assessing microplastics eco-toxicity and their impact on biota, economy and natural value [63].

Recycling is one of the main pillars of plastics' circular economy. Some polymers can be pre-sorted, processed, melted, extruded, pelletized and reprocessed into novel products. However, not all plastics are recycled due to a lack of economic viability and technical barrier solutions [64]. Several EU-funded projects have focused on upcycling marine litter and derelict fishing nets, such as BLUENET [65], OCEANETS [66], MARELITT [67], SEACYCLE [68]. For example, some companies have established yarn production by recycling fishing gears [69][70][71]. Yet, recycling alternatives are not developed for microplastics due to the stock limitation [72], highlighting the urge to design microplastic-free products and reduce the sources of secondary microplastics. It is noteworthy that the plastic recycling process could be less sustainable than using virgin plastic when elevated consumption of non-renewable energy and long-transportation routes are needed [73][74]. Nevertheless, limitations to the recycling process, such as high costs, alloy complexity and limited mechanical properties, could be overcome by microbial technology that transforms plastic waste into high-value products [75].

Extended producer responsibility (EPR) imposes accountability over the entire life cycle of products and packaging introduced onto the market, making manufacturers responsible for the products' end-of-life [43]. EPR encourages the development of easily reused/recycled products requiring fewer resources and fewer hazardous substances. The partnership between Adidas and Parley is an example of EPR that resulted in 30 million shoes produced from plastic debris at the end of 2020 [76]. However, developing flexible EPR strategies within fragmented plastic governance is challenging [77][78], and when it comes to microplastics, addressing producer physical responsibility is still an intricate task [79].

2.2. Behavioral Changes

Behavioral changes and multi-layered governance among general citizens, governments, industries, NGOs, academia, fishers and local communities are fundamental to the prevention of the leakage of microplastics into the environment [80][81][82]. Thus, promoting environmental literacy among youths [16] and adults [83], as well as engaging stakeholders to advocate the reduction of plastic pollution, are essential strategies to tackle littering [84]. Anti-littering campaigns, such as "Basuraleza" in the Basque Country [85], and "Keep Britain Tidy" in the UK, can be underlined as behavior-shifting efforts [42]. More specifically, the tailored ocean literacy tools could help to reduce microplastic contamination. For instance, the ResponSEAble project (https://www.responseable.eu/, accessed on 6 December 2020) tools successfully raised awareness among participants, triggered behavioral changes and minimized microplastic contamination from cosmetics and ballast water [86].

In light of this urge for behavioral changes, the Dutch government proposed to raise awareness of microplastic pollution in 2016 by fostering research, elaborating public procurements, enhancing media outreach and including microplastics as pollution indicators in abrasive cleaning agents of international certifications [87]. Furthermore, Belgium developed a system to stress where industries could reduce primary microplastics use throughout their production system [88]. Those actions combined with the worldwide concern of microplastic pollution have led to the ECHA proposal of a wide-range restriction on microplastics in Europe. When successful, this proposal will prevent the release of 500,000 tonnes of microplastics in the next 20 years [89].

Lack of knowledge is a hurdle to any behavioral changes. Citizens are generally unaware of microplastics pollution. However, Henderson and Green (2020) point out that some know about microbeads present in personal care products due to media outreach. However, only a few correlate their use of personal care products with microplastic pollution in the environment, highlighting that environmental awareness is more effective when the content aligns with the values and realities of people [90].

Media strategies and educational films emphasizing the issues arising from microplastic could increase social engagement [90]. Moreover, mediatic campaigns linked to academic measures, e.g., MOOC on Marine Litter [91] and Ocean Plastic Webinars [92], could support policymakers to trigger long-term behavioral changes through moral obligation [60]. Although the media strategies are often related to the aquatic environment, these media efforts should target all environments (e.g., aquatic, aerial and terrestrial ecosystems) due to microplastic ubiquity.

2.3. Bio-Based Polymers

Bio-based plastics are another response discussed by stakeholders to minimize fossil fuel overexploitation and to prevent pollution from oil-based plastics [93]. Even though the former represented only 1% of the current total annual plastic production (2.1 million tons in 2019) [93], the bio-based polymers are recently gaining more attention. Several bio-based polymers with efficient mechanical properties can be produced using direct fermentation of blended starch and other raw materials, such as polyhydroxyalkanoates (PHAs), polylactic acids (PLAs) and polyhydroxybutyrates (PHBs) [64]. Some of these polymers, e.g., PCLs, PHAs and PHBs, can be produced from sewage sludge and further incorporated as biopolymer and hard packaging products [94]. That may represent a potential strategy to recycle waste and reduce plastic contamination. Furthermore, chitosan [95], pectin, starch, lignin [34][96] and jute fiber [97] are other bio matrices under investigation worldwide with the potential to occupy the plastic market in the coming years.

Bio-based polymers have been used successfully for fishing gear making [98][99][100]. However, bio-based polymer production and use are still under debate [101][102][103] due to high costs (2–4 times more than oil-based plastics) [64], non-ideal mechanical properties, lack of waste management infrastructures, water footprint and substantial land use [104]. Moreover, the transition towards bio-based plastics may be misleading since not all bio-based plastics are biodegradable, e.g., bio-PE [105].

2.4. Market-Based Instruments (MBIs)

Regulatory MBIs impact behavioral changes toward plastic littering and microplastics contamination [106]. These instruments estimate the externalities derived from plastic littering, considering their improper management costs and the urge for revenue-raising policies, rewards and incentives to retrieve these pollution costs [107]. Considering these externalities in products' prices is essential to assuring that the stakeholders are dealing with full costs. Here, MBIs with the potential to prevent microplastics are discussed.

- Green procurement: Environmental considerations are integrated into procurement decisions, for instance, a seaside community requiring restaurants to use only reusable plates, cups, and cutlery [10], or Nordic countries proposing a joint investment in recycling infrastructure [108].

- User/Consumer/Beneficiary pays: A levy is applied to users/consumers using products that are harmful to the environment or citizens receiving a benefit. For example, a user of a clean beach contributes to beach clean-up, or users must pay a 10% fee on the use of plastic bags (in Portugal this measure led to a decrease of about 60% in plastic bag consumption per person per shopping trip [33]). However, these measures tend to fail without well-implemented monitoring systems [82].

- Polluter pays principle (PPP): Polluters are responsible for addressing pollution. That encourages companies to find alternatives within their manufacturing processes [109], e.g., the Alliance to End Plastic Waste will invest up to USD 1.5 billion over the next five years on projects targeting a plastic-free ocean [34], and Extended Producer Responsibility (EPR) to achieve zero plastics in landfill by 2025 in Europe [110]. Regarding microplastics, the polluter can pay for mitigation strategies, such as research on eco-design or innovative cleaning-up initiatives [111] and microplastic removal from WWTP [112].

- Deposit-refund programs: Strategy already implemented in several countries to encourage citizens to return containers that can help prevent the entry of such objects into the environment, e.g., returnable beverage bottles. The deposit–refund systems in Denmark, the USA, Canada and Australia for bottles are a success and could serve as a benchmark for worldwide implementation [113].

- Incentives/subsidies: Mechanisms that maintain prices below market levels for consumers or higher than market levels for producers. Examples include the fishing gear buyback program (700 tons of waste recovered in South Korea between 2007 and 2011 [114]); fiscal subsidies to recycling companies, fishers and other enterprises using recycled material [106]; and the European Maritime and Fisheries Fund promoting the Fishing for Litter activities [19][98].

- Liability/Fines/Charges/Fees/Taxes/Bans: Constant reinforcements and audits can discourage microplastics use during manufacturing. Although tracing back the microplastic producers is a strenuous task, especially in developing countries, the money acquired from fines [10], SUP surcharges and other liabilities could be invested in alternative upstream responses.

- Banning SUP: Bans on SUP commodities, such as plastic bags and plastic-based microbeads, have the potential to prevent microplastics pollution from both primary and secondary sources [58][115] and to disrupt consumers' behavior by undermining the possibility of acquiring SUP [116]; however, the unintended impacts of bans should be meticulously reviewed beforehand, e.g., impacts of disposable paper cups with plastic coating [117].

- Ecolabeling: Reduce the adverse environmental impacts of products and raise awareness among consumers when purchasing products [118]. Ecolabels are only given to products respecting strict criteria and are regulated (ER Regulation 66/2010 on EU Ecolabel). For instance, rinse-off cosmetic products with microplastics cannot acquire the EU Ecolabel [87], and only products containing an elevated proportion of recycled plastics obtain the Nordic Swan Ecolabel [64]. Although imposing ecological requirements can represent a solution to cope with this issue, consumers would seldom choose labeled microplastic-free products when the label comes along with an additional "ecological" cost [118]. However, microplastics-free labels convey information about companies' environmental consciousness and enforce the idea of communicating political and ethical preferences through conscious consumption [118].

- Private governance: MBI efficiency tackling microplastics is only feasible with non-fragmented governance involving third-party organizations [119][120]. Even though challenging certification systems could be used as transnational instruments for environmental standards through the orchestration of several actors and directives, certification labels to prevent microplastic pollution are not as effective as top-down governance methods encouraging consumers to pay more for eco-friendly alternatives through state regulatory frameworks [118].

2.5. Primary Microfibers from Clothing

Primary microfibers are constantly released by the clothing industry, from the manufacturing stage to the washing cycles [121][122]. Microfibers formation depends on the type of polymer used in the textile [123], the cutting process [124], washing machine type, washing cycles selected and the clothing age [125]. To cope with this issue, thin coating fabrics made of silicon or bio-based materials could reduce microfiber loss by about 30% [126]. Moreover, three pre-washes, superimposed filter meshes and detergent use could reduce >53% of microfiber emissions [127]. LUV-R filter and Cora Ball, technologies already available in the market, could capture 87% and 26% of microfibers by count in the wash [128], and XFiltra filter and Guppyfriend bag could reduce 78% and 54% of microfibers loss, respectively [123]. However, these strategies demand time and care from users, impacting their comfort. That highlights the need to develop a filter already connected to the washing machine.

Even with such improvements, about 15 thousand tons of microfibers would still be released into the environment [125]. Hence, engaging the textile sector and washing machine manufacturers as well as sharing the technological advances and establishing protocols for monitoring fiber loss is necessary to palliate the microplastics released from clothing garments [121].

2.6. Tire and Road Wear Particles (TRWP)

TRWP can represent up to 5.5 kg of microplastics per capita per year to the surrounding environments [129]. In the USA this accounts for 1,120,000 t/y, and in the European Union, 1,327,00 t/y [130].

Investments in infrastructure, maintenance, monitoring and alternative materials stand out as a measure to prevent the emission of TRWP microplastics. For monitoring purposes, the following strategies are suggested: (1) standardize methodologies to provide a holistic picture of TRWP emissions; (2) define emission factors of TRWP release; (3) assess either mileage or tires' average weight loss; and (4) set specific biomarkers to calculate the amount of TRWP in environmental samples [129][130]. For maintenance, several improvements are proposed: (1) correct wheel alignment and balancing [129]; (2) the prevention of studded tire use through taxes [131]; and (3) wear-resistant tires with design improvements (e.g., tires with silica as filler and tires resistant to degradation from physicochemical stressors [132]). Additionally, ModieSlabs, an innovative concrete pavement, and other prefabricated concrete pavements, can reduce up to 50% of the TRWP emissions compared with asphalt roads [87]. The use of infiltration bases to retain microplastics are also recommended, i.e., gully pots, filter strip, infiltration chamber systems, perforated pipe with a stone-filled trench, or even bio-retention systems and rainwater harvesting [131]. Other studies highlight the urge to enhance runoff treatments and drainage systems [129] or to install gutters connected to the sewage system along the roads [87].

2.7. Antifouling Paints

Antifouling coatings used by both the fishing and shipping industries reduce vessels' drag resulting from fouling. These coatings usually release microplastics into the environment. To prevent this source of pollution, mandatory regulation to control the emission during abrasion and further paint innovation, such as silicon-based and other antifouling agents, is needed [133]. The following measures are also pivotal to preventing microplastic emissions: avoidance of excessive antifouling coating and dust spreading during coating removal; surface sanding and priming indoors; constant cleaning and maintenance to minimize peeling off processes and contamination from brushes/rollers; and awareness-raising among crew members. Furthermore, efforts are needed to improve the paint wear resistance, to replace the microplastics with more environmentally friendly agents and to develop products (catalysts) to optimize paint degradation rates [87].

3. Downstream Strategies to Mitigate Microplastics Pollution

3.1. Degradation of Microplastics

Plastic degradation occurs by different means. Plastic photodegradation requires only sunlight and oxygen to trigger plastic deterioration and hole formation. Innovative photodegradation has focused on the degradation of high density polyethylene (HDPE) microplastics by two semiconductors based on N–TiO_2 [134] and the partial degradation of LDPE films through visible-light-induced plasmonic photocatalysts with platinum nanoparticles deposited on zinc oxide (ZnO) nanorods [135].

Macro-organisms have also been described as potential biodegrading agents. Caterpillars of the wax moth (*Galleria mellonella*) [136] and isolates from *Lumbricus terretris* gut microbiota were reported as PE degraders [137]. PS mineralization was elicited by *Tenebrio molitor* Linnaeus microbiota [138].

Numerous microorganisms were already reported as plastic degraders. *Alcanivorax borkumensis* may degrade LDPE [139]; *Zalerion maritimum* ingests PE [140]; *Ideonella sakaiensis* 201-F6 consumes PET [141]; *Rhodococcus* sp. biodegrades PP; *Aspergillus* sp. colonizes HDPE surfaces; *Pseudomonas* and *Alcanivorax* act on PCL; *Vibrio alginolyticus* on PVA-LLDPE and Muricauda sp. on PET [142]; and the strain TKCM 64 and *Lactobacillus plantarum* (MTCC 4461) were reported on PCL [143]. Actinomycetes, Rhodobacteraceaes, *Mucor rouxii* NRRL 1835, *Streptomyces* bacteria and *Aspergillus flavus* biodegrading potential was also documented [75][144][145].

Numerous biodegradation studies are centered on *Pseudomonas* and *Bacillus* since they can trigger polymeric chain scission and partially degrade brominated high-impact PS [146], HDPE/PE [147], LDPE [148] and PVC [99]. The enzymes excreted by *Pseudomonas* sp. AKS2 can degrade the biopolymer polyethylene succinate (PES) at a rate of 1.65 mg d-1 [149]. The engineered *Bacillus subtilis* strain had shown high PETase activity [150]. According to Auta and colleagues, *Bacillus cereus* can reduce PS microplastics to its half in 363 days, and *Bacillus gottheilii* exemplified a multi-plastic degrader since it colonized PE, PET, PP and PS [151].

Several uncertainties remain regarding biodegradation efficiency and scaling it up. For instance, the efficiency of waste collection systems to handle biodegradable polymers, rates of GHG emissions in landfills, the role played by contaminants attached to plastics in compost quality, shelf-life of biodegradable packaging, land-use to sustain bio-based plastics [60] and the actual assimilation of plastic carbons into microbial biomass, CO_2, or CH4 [152]. A more detailed perspective can be seen in the authors' perspectives section.

3.2. Waste to Energy

Waste to energy (incineration) is often the solution left for a polymer with difficult recyclability [153][154]. Some polyolefins, thermoplastics and polyesters can be transformed into fuel and energy through microwave pyrolysis [110], co-pyrolysis or catalytic pyrolysis processes [72]. The recovered constituents can result in chemicals and asphalt quality enhancers, e.g., carbon black [155], or be upcycled into carbon nanotubes [156]. Moreover, integrated carboxylic oxidation and hydrothermal hydrolysis could activate peroxymonosulfate as a reactive radical to decompose plastics into intermediate organic matter to enhance algal biodiesel development [157]. Although more sustainable than overexploiting fossil fuel [158], this process demands cost-prohibitive technologies typically unavailable in small communities [25]. Currently, incineration represents a reasonable alternative for complex waste streams, such as marine litter [159].

3.3. Water Treatment Plants

Wastewater Treatment Plants (WWTP), Integrated Solid Waste Management (ISWM), Drinkable Water Treatment plants (DWTP), landfills and sewage treatment plants (STP) collect microplastics and mitigate microplastics emissions into the environment. Modern WWTP can retain >90% of the microplastics arriving in their facilities [160][161][162], and DWTP presents high retention rates [163]. These industries employ the following technology to retain microplastics.

- Membrane bioreactor (MBR) is considered the most effective technology for removing microplastics (>98% removal efficiency). Microplastics are also retained in the sedimentation [112][164] and coagulation-flocculation processes, which retain more than half of microplastics content [72].
- Rapid sand filtration, ozone treatment and reverse osmosis also retain microplastics [72][112][160].
- Filters (e.g., granular activated carbon, carbon block faucet and reverse osmosis filters) are efficient for recovering microfibers, and air flotation combined with activated sludge technologies can remove microplastics from the WWTP sludge [165].

The retained microplastics become part of the biosolid. Considering the elevated accumulation of microplastics in WWTP biosolids and their application as organic fertilizer in agricultural lands, several alternative applications stand out, e.g., bio-bricks [166]. Nevertheless, efforts are needed to make these techniques cost-effective and efficient in assessing the fragmentation of microplastics into nanoplastics in these processes [163]. Intensified R&D in microplastics in water treatment plants tends to increase since the proposal (TA/2019/0071) that includes microplastics as a water quality criterion in Europe [167].

3.4. Cleanups and Removal Strategies

Continuous cleanups to avoid plastic accumulation on shorelines are effective, even on a minor scale, for reducing the amount of plastic, microplastics and additives in the environment [168]. Although scarce cleanups are exclusively targeting microplastics [169], microplastic contamination is mitigated when macro litter is removed. The Ocean Conservancy International Coastal Cleanup [170] and the Zero Plastiko [171] are worth mentioning due to the high social commitment and awareness-raising events.

Specific microplastic removal strategies include the GoJelly prototype made from jellyfish mucus to retain microplastics [172]; the Clean Swell application from Fighting for Trash Free Seas that connects citizen scientists worldwide to cleanups [173]; the "Mr. Trash Wheel" in Baltimore [128]; and giant drain socks to trap litter in the mouths of Australian stormwater drains [174]. Furthermore, Ocean Cleanup® developed an u-shaped system to trap floating marine litter from garbage patches and an interceptor for polluted rivers in Indonesia, Vietnam, Dominican Republic and Jamaica, and intends to transform the collected marine litter into revenue [175][176].

4. Fisheries and Aquaculture as Examples of Multifaceted Responses to Both Preventand Mitigate Microplastics Pollution

Fishing for litter (FFL) is an effective response that engages fishers to retrieve marine litter both passively (voluntarily litter collection during commercial fishing) or actively (funded by incentives or as a service) [177]. However, FFL, particularly active FFL, can be costly [177][178][179].The activity is, therefore, recommended for areas with confirmed presence of floating marine litter structures, such as marine litter windrows (Ruiz et al., 2021). Then, the fished litter could be reinserted into the market [180] or transformed into energy [16]. The following are some potential applications within the fishing and aquaculture sector to deal with marine litter: Gear tagging and tracking; technologies with less net contact with the seabed; deployment practices; enhanced management; enforcements in controlling illegal fishing/dumping; improvement of port reception facilities; strict towing control [25]; resistant bio-based fishing nets [100][180]; educational programs for fishers [181]; and risk assessments of nearby fish farms [182]. The aquaculture sector also started to propose solutions to deal with marine litter [183]. For instance, the Aquaculture Stewardship Council has planned to ask certified producers to perform risk assessments of potential plastic pollution and to implement mitigation actions to diminish the producers' impacts [184][185].

5. Conclusions

This entry summarizes the current knowledge on policies and strategies to prevent(upstream responses) and mitigate (downstream responses) microplastics pollution, addingvalue to existing literature. Here, researchers highlight the importance of integrated governance,the inclusion of microplastics in policymaking and the urge for enforcement to cope withthis multi-layered environmental issue. Microplastics have already been included inseveral policies worldwide, 17 years after the first use of the term microplastics. This legalrecognition of both microplastics and nanoplastics, combined with legal enforcement, isexpected to increase in the following years. Researchers expect the responses and possible solutionspresented here to serve as an updated baseline for policymakers and stakeholders to tacklemicroplastic and plastic pollution.The 2010s boom in policies tackling microplastics raises some key questions. Are researchers measuring whether policies' implementation is preventing or mitigating microplastics contamination in the environment? Is there a holistic picture of the increase, stabilizationor decrease of microplastics entering the environment over the past decade? Are theXXI century policies marking a turnaround or dip in microplastic pollution? Numerousgrants were distributed worldwide to tackle microplastics contamination, but is thereany reliable monitoring plan that shows, in fact, the decrease of (micro)plastics in theenvironment? Since plastic production worldwide is still increasing and more than one-halfof all the plastics ever produced have been made since 2000, it is unlikely that the boomin policymaking after the 2010s was sufficient to bring down the levels of (micro)plasticpollution in the environment. Researchers urge effective monitoring to assess how the top-downpolicymaking established in this century resonates with the amount of (micro)plastics foundin the environment. Without proper monitoring, (micro)plastic pollution may culminate inan unsolved and outdated environmental concern.It is intelligible that preventing microplastics from entering the environment should bea priority over cleaning them up, which is cost-prohibitive, technically challenging or sim-ply not beneficial to the environment. Although upstream responses stand out, they shouldnot completely eclipse downstream responses, which are also needed. Comprehensiveand operational legislation/regulations are required as groundwork to actively preventmicroplastics from entering the environment. It is infered that the way forward to regulatemicroplastic pollution in the following decades is to strengthen the policymaking to stopmicroplastic from entering the environment and enforce already existing top-down policies.A circular economy stands out as the chief solution to reduce microplastics contamination. Policies and initiatives tackling some SUP, such as plastic cutlery, have been an inflec-tion point regarding plastic pollution in the environment. Strengthening these policies andextrapolating them to microplastics is necessary. This encouragement could be carried outthrough harmonization of legal instruments, market liability, investments in alternativematerials, eco-design, EPR schemes, including externalities in products, microplastic-freelabels and constant inspection of regular businesses. Environmental and socioeconomicbenefits can be foreseen when incentives trigger the development of alternatives to oil-based plastic. Behavioral changes towards microplastics at all societal levels need to befostered through environment literacy and engagement of different stakeholders throughbehavior-shifting efforts linked to mediatic campaigns.Source-specific upstream responses can also act as potential preventive measures.Textile sectors and washing machine manufacturers will have to palliate the release ofmicroplastics from clothing garments. Further research should also focus on alternativematerials and technologies to replace tires' synthetic rubber, the plastic coating used inantifouling painting, along with other sustainable alternatives. Nevertheless, it is pivotal torestate that plastic pollution is intertwined with other environmental issues. For instance,blindly banning plastic mulch in agricultural soils, may lead to decreased productivity,increased pesticide application, higher water use, etc. Hence, life cycle assessments are fundamental to avoid a "one fits all solution" and highlight the need for solutions tailoringthe specific circumstances and applications.

Regarding mitigation measures, investments are recommended in integrated wastemanagement programs with technological advancements and tertiary treatments, whichcould also enhance health quality and living standards in developing countries. Moreover,biodegradable polymers and microbial degradation, often presented as potential solutions,need further thorough research since biodegradation rates depend on different propertiesand complexity of the receiving systems, i.e., plastic films claimed as biodegradable undercontrolled environments may not degrade or last longer in natural environments. Thecost-efficiency of these solutions ought to be evaluated as well. In another perspective, severalcrucial questions remain unanswered: (1) Are microorganisms consuming microplasticsonly under starvation? (2) To what extent are microorganisms indeed biodegrading andassimilating microplastics instead of only fragmenting them? (3) What are the consequencesof plastic biodegradation on the environment regarding additive leaking, nutrient use andmicrobiome changes? (4) Are these degradation techniques cost-efficient solutions for allpackaging or only plastic intended to finish its use in the environment? Further empiricdata is needed to tackle those unanswered questions.To sum up, the upstream and downstream responses discussed here could enhancethe baseline used by the United Nations and the other stakeholders involved to target (mi-cro)plastic pollution. Researchers emphatically urge a wide-ranging assessment of how the policiesimplemented after the 2010s have helped to reduce the (micro)plastics in the environment.Then policymakers could decide whether to strengthen, reinforce or replace the existingpolicies. It is pivotal, however, to consider plastic pollution as an additional anthropogenicfactor undermining the planetary boundaries instead of an isolated issue. Therefore, it isfundamental to consider climate change, land use and cost-efficiency throughout the entireprocess to implement upstream or downstream responses to tackle plastic pollution.

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