













Opinion

COST Action PRIORITY: An EU Perspective on Micro- and Nanoplastics as Global Issues

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Abstract: Plastic fragments, weathered into or released in the form of micro- and nanoplastics, are persistent and widespread in the environment, and it is anticipated that they have negative environmental impacts. This necessitates immediate efforts for management strategies throughout the entire plastics lifecycle. This opinion paper was initiated by the EU COST Action CA20101 PRIORITY, which focuses on the need to develop an effective global networking platform dealing with research, implementation, and consolidation of ways to address the worldwide challenges associated with micro- and nanoplastics pollution in the environment.

Keywords: microplastics; nanoplastics; hazard assessment; remediation; mitigation; analytical procedures; harmonization; metrology; regulatory science; risk management

1. Introduction

The production and demand for plastics have grown over the last century, leading to ever-increasing quantities of plastic waste globally. Plastic provides countless benefits to modern life through their light weightiness, high strength to weight ratio, durability, and

low cost. As a result of this unique set of properties, plastic has displaced and replaced many conventional materials such as glass, wood, or paper, leading to a rise in its production from 1.7 million tons in 1950 to 368 million tons in 2019. Europe accounts for 16% of global plastics production, which is expected to double in the next ten years. In 2018, approximately 25% of plastic waste was recycled while the remainder was incinerated or ended up in landfills [1]. However accidentally or intentionally, some fraction of this plastic waste is mismanaged and is released into different environmental compartments. This includes aquatic and terrestrial environments, with soil being one of the major sinks [2], although by far the least studied. It was estimated that of the approximate 275 million tons (Mt) of plastic waste generated in 192 coastal countries in 2010, between 4.8 to 12.7 Mt entered the ocean [3]. In the absence of appropriate waste management infrastructure improvements, this amount is expected to increase by an order of magnitude by 2025 [3]. Plastic is reported to account for over 80% of marine litter [4,5]. The worldwide coronavirus pandemic made matters even worse, due to the large quantities of the single-use plastic protective equipment such as gloves and masks, which were frequently improperly disposed of. The spread of coronavirus also increased the demand for packaging of food/non-food products as a consequence of the increased e-commerce and home delivery systems for enhancing safety [6,7].

Plastic litter discharged into the environment is subjected to different degradation and fragmentation phenomena depending on the physicochemical properties of the polymers and on the environmental conditions in which the materials are exposed to heat, UV radiation, oxidation, biofouling, and mechanical forces. These processes result in the generation of small particles, designated as microplastics (MPs). In 2008, during the “International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris”, MPs were classified into primary MPs, i.e., those that are intentionally produced either for direct use or as precursors to other products as microbeads, micro flakes, or nurdles, particularly for use in various products such as cosmetics or air-blasting technologies [8], and secondary MPs, i.e., those formed in the environment due to the degradation of larger plastic material [9,10]. Alternatively, the same terminology has been used to identify primary MPs, not only as particles produced in a sub-millimetric size for a specific application, but also as particles originating from the abrasion of large plastic objects during manufacturing, use, or maintenance [11] as MPs released from synthetic fabrics due to mechanical and chemical stresses during washing, or MPs released from wear and tear of car tires [7,8]. The different usages of terminology, and the different ways to classify MPs in general, is still an open debate [12], highlighting the need to further discuss MPs definitions.

The increasing generation of both primary and secondary MPs, coupled with both human and environmental exposure to them, is a major concern since their potential to impact human and ecosystem health remains largely unknown to date [13–16].

Macro-sized litter (>5 mm) accounts for a major portion of plastic in the marine environment by mass (kg/km^2), but MPs are responsible for a larger proportion by number i.e., items/ km^2 [17]. Of the plastic litter entering the oceans, the plastic material in the form of MPs potentially exhibits high bioavailability to aquatic animals and interactions with organic and inorganic pollutants, present in the surrounding environment, due their small size combined with a large surface area that facilitates adsorption/interaction phenomena [18,19]. They represent a potential threat to a variety of organisms, both aquatic and terrestrial, ranging from zooplankton, to bivalves, up to vertebrates [13,20]. The negative effects of MPs are not only limited to physical parameters but extend to chemical factors due to their ability to adsorb, accumulate, transport, and desorb contaminants from their surrounding environment, or leaching of chemical components added during their manufacturing process [21].

Weathering-related degradation results in myriad changes depending on polymer type and environmental conditions; loss of mechanical integrity, embrittlement, degradation, and fragmentation into smaller pieces down to the nanoscale range, abiotic and/or biotic

degradation. Some of these plastics, i.e., biodegradable plastics, can be degraded via microbial actions, leading to their ultimate conversion into carbon dioxide, methane, or other naturally occurring compounds; this process is known as mineralization. However, the rate of such biological processes depends on environmental factors as well as on the chemical structure of the polymer backbone. Hence, the number of plastics that are degradable under natural conditions is relatively limited and a wide range of degradation trends, degradation kinetics, mechanisms, and levels have been observed [22].

Nanoplastics, NPs, categorized as sub-micron-sized plastics [12], are considered contaminants of emerging concern. They are hypothesized to interact and affect living organisms differently compared to larger sized plastic debris, since they may be more easily taken up by organisms, could be more toxic to cells, more easily pass through biological barriers, and may cause oxidative stress and cell death [23]. Moreover, NPs may have the potential to transport further through the environment than larger plastic items due to their smaller size. However, there is still limited understanding of NPs risks to both humans and the environment due to (1) difficulties in establishing actual exposure concentrations, as their size makes isolation from complex environmental matrices challenging and there is a lack of analytical methods for their full characterization, and (2) limited studies on biological effects, especially under “real-world” environmentally relevant conditions [24].

2. Current Strategies to Deal with the N/MPPs Challenge

Due to the complexity of the nano- and microplastic (N/MP) pollution challenges, different strategies are under evaluation to mitigate these environmental pollutants and to prevent N/MPPs from entering the environment. These strategies include:

- Integrated plastic management approaches, including reducing, reusing, recycling, and recovering plastic waste, supporting the transition to a circular economy, which would minimize the stock of mismanaged plastic waste which could degrade into N/MP.
- Technological solutions for the valorization of plastics wastes into chemicals and/or fuels, and so on [25].
- Sustainable coatings to reduce/retard the microplastic release from polymeric substrates [26,27].
- Advanced oxidation technologies to improve degradation of micro- and nanoplastics [28,29].
- Replacement of nondegradable polymers by biodegradable polymers which will degrade under defined conditions (e.g., composting) or release into the environment (aquatic or terrestrial) in due time [30].
- Efficient treatment processes, specifically technological (catalytic) solutions for the breakdown and removal (mineralization) of N/MPPs, as additional tail-effluent treatment stages, e.g., in wastewater treatment plants, WWTPs [31,32].
- Development of innovative materials and devices able to sorb/filter microplastics in the aquatic environment [33].

In addition, regulations have been adopted or are under development which aim to ban, restrict, or introduce levies on certain types of plastic products. Optimizing the balance of several facets of plastics production, use and waste management are necessary to alleviate the growing plastics environmental waste issue [34]. The technological solutions and strategies adopted by policymakers and governments around the globe to reduce the generation of plastic wastes will ultimately reduce emissions of N/MPPs.

3. Future Needs for Addressing the N/MPPs Challenge

Environmental pollution with N/MPPs poses serious challenges for the 21st century. Scientists, risk-managers, and, above all, decision-makers and industries must be strongly committed to achieving reduced exposures and minimizing hazards. Citizens, on the other hand, need to be correctly informed of the risks N/MPPs pose to the environment and human health. Ultimately, they can be driving forces of the required societal changes and demand actions to reduce the amount of plastics released into the environment [35].

In 2009, the proceedings of the first International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris were published. Subsequently, the number of scientific publications and data on the topic have grown exponentially. Understanding the real impacts and validating the alternatives to plastics with realistic solutions to the related issues of plastics pollution are necessary for decision-makers and plastic industries alike. The scientific community plays a key role in providing reliable and comparable data, based on robust and transparent methodologies. The only way to achieve this result is through extensive networking amongst researchers together with the involvement of industry experts.

Decision-makers urgently need consistent metrics and definitions to guide and prioritize actions at several levels, from sustainable product design and efficient regional infrastructure to suitable policies and enforcement [34]. Thus, efficient metrics valuing plastic pollution must be identified to guide sound eco-design and waste management policies; an important issue is the assessment of sustainable polymers and their persistence in the environment.

Among the organizations providing standards on plastics, the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) have developed 700 and 500 standards on plastics, respectively, with 180 projects underway. Recently, specific committees and working groups were established to develop standards on the environmental aspects of microplastics. However, only in 2020, ISO defined MPs as “any solid plastics particle insoluble in water with a size ranging between 1 μm and 1000 μm (= 1 mm)” while NPs are defined as “plastics particles smaller than 1 μm ” [36], and these definitions are still controversial. Much work is required, and researchers in the field urgently need an action to share and compare their knowledge and findings. To help and support pre-normative research, The Versailles Project on Advanced Materials and Standards (VAMAS) has established a new technical working area (<http://www.vamas.org/twa45/>, accessed on 22 April 2022).

In recent years, an increase in research funding to a diverse group of new research projects has led to a better understanding of the impacts and implications of plastics, improving the knowledge on the occurrence of N/MPs in different environmental compartments, and preliminary risk assessments have been performed. Many thousands of funding agencies have been acknowledged in research papers devoted to N/MPs issues (Web of Science/Scopus search, which also includes local agencies). More than 7000 research papers and 1000 reviews have been published regarding N/MPs (Scopus, 2012–2022, keywords restricted to “microplastic(s)” or “nanoplastic(s)”), mainly devoted to the quantification of their presence in different environmental compartments, the evaluation of their effects and risks for aquatic and terrestrial biomes, the assessment of their bioaccumulation and the effects of associated chemicals, and the modeling of their environmental behavior. However, these research areas need novel interdisciplinary approaches to overcome the limitations of the conventional procedures, and to coordinate research efforts to minimize unnecessary duplication of work. The development of techniques and concepts primarily requires coordination and harmonization of different research areas from both public and private stakeholders. In this context, the COST Action CA20101 PRIORITY (“plastics monitoring detection remediation recovery”) was initiated upon the agreement of 85 secondary proposers from 25 countries. COST (European Cooperation in Science and Technology) Actions are bottom-up networks connecting research initiatives across Europe and beyond. PRIORITY focuses on strategies to tackle the global challenge of micro- and nanoplastics in the environment (<https://www.cost.eu/actions/CA20101/> and <https://ca-priority.eu/>, accessed on 22 April 2022). PRIORITY was approved on 25/05/2021 by the COST Committee of Senior Officials, with the official start date on 19 October 2021 and a duration of four years. The Management Committee (MC) is the committee responsible for the management of the Action, reflecting the intergovernmental character of COST. Nomination to the Action MC is based on national rules and procedures (up to two representatives for each State

admitted to the COST Association). In February 2022, the PRIORITY MC was composed of 54 members from 32 countries.

4. PRIORITY Approach for Addressing Future N/MPs Challenges

Close interdisciplinary cooperation amongst those working in the fields of natural and life sciences, together with social, behavioral, and regulatory disciplines, is the only way to consolidate information which has already been generated and address the unexplored risks and solutions related to N/MPs. Indeed, the lack of quantitative evidence of N/MPs hazards and exposure does not allow conclusions on the risks related to them. Thus, the scientific community needs to develop a deeper understanding of the interactions and distribution and assess the hazards of N/MPs in each environmental compartment and for public health. It will be essential to implement both agreements and legislation to handle the risks, focus on emissions reduction, and to develop less hazardous materials.

- PRIORITY proposes to drive scientific efforts for addressing future N/MPs challenges through:
- Identification of new strategies to design sustainable plastics as alternatives to these persistent plastics and related N/MPs.
- Identification of mitigation strategies and approaches.
- Design of new workflows to reduce plastics leakage and impacts to the environment.
- Development and optimization of standard protocols for N/MP sampling and measurement procedures and assessing biological hazards.
- Ensuring high confidence in measurement results.
- Assessment and validation of robust measurement procedures for qualitative and quantitative analysis by interlaboratory studies.
- Drawing attention to the importance of reference materials (certified and uncertified) for method validation through the identification of available reference materials and making suggestions for further developments of candidate reference materials with the goal of reaching certification following ISO documentation.

The entire chain through N/MPs environmental pollution, from monitoring to the development of mitigation strategies to reduce N/MPs pollution, requires the development of reliable and sustainable technological solutions. All efforts will focus on spreading shared technologies to provide open access for as wide a circle of researchers, technicians, laboratories, agencies, and industries as possible through:

- The identification of needs and entry barriers related to cost and performance.
- The modification and/or improvement of existing instrumentation.
- The identification of the needs for new tools and devices.
- The development of reference materials for method development, calibration, and quality control.
- The definition of the EU roadmap for N/MPs critical issues for the environment.
- PRIORITY contributions will enhance:
- Trans- and interdisciplinary exchanges among stakeholders who will benefit and contribute to the growth of the knowledge in the field.
- Dissemination of protocols for N/MP sampling and measurements.
- Strengthening links between industry, academics, decision-makers, and the general public.
- Raising public awareness by disseminating data in an easy-to-understand format on environmental and health issues related to N/MPs.

It is necessary to flag the most relevant areas which could be candidates for suitable policy measures in different environmental compartments. Mitigation measures may be supported by legislation but also through voluntary agreements and softer awareness-raising, communication, and education actions. Indeed, companies may replace plastic products with more sustainable alternatives or find technical solutions for lower emissions if this change would be driven by economic advantages, and people's behavior can change

in response to new circumstances and media communications. Citizens and organizations may alter their behavior if they are motivated and if feasible alternatives are available.

From a global governance perspective, the discussion on N/MP pollution is essential. It is mandatory to reach international consensus on how to manage and tackle plastics pollution throughout the entire plastics lifecycle based on the scientific data and, on this evidence, to reach specific agreements on how to minimize and handle those challenges specifically related to N/MP. PRIORITY will support actions to reach these targets by sharing research results, exchanging information amongst experts, and helping to develop public awareness and education. Such targets, as well as generation and access to standardized N/MP pollution data and health effects, are a relevant step for future international agreements on N/MP issues.

5. Outlook

Seven working groups (WGs) will coordinate and perform the tasks required by the Action to fulfil the objectives of the network project plan to cope with N/MPPs challenges. This will be achieved through specific objectives, named research coordination and capacity-building objectives. Research coordination objectives entail the distribution of tasks, sharing of knowledge and know-how, and the creation of synergies among Action participants to achieve specific outputs. Achieving these objectives turns the COST Action from initially scattered groups into one transnational team and leverages the existing funded research. Achieving capacity-building objectives entails building critical mass to drive scientific progress, through the training of European stakeholders, increasing capability in the study of micro- and nanoplastics, and connecting and strengthening collaborations. Through diverse yet highly interconnected WGs, we propose to bridge different research fields for more impactful and holistic discussions and actions regarding N/MP environmental pollution and hazards. Each WG has clear objectives and activities, namely:

WG1 Impacts and risks on human health and environment related to N/MPPs

WG1 is expected to identify, develop, and, hence, increase the European and world-wide standardization of hazard testing methods for N/MPPs. This includes different environmental exposure matrices. Moreover, it aims to outline and disseminate the main challenges and research priorities. Short-term activities will include the definition of the state of the art, the expertise, and the ongoing activities of the Action participants, in order to develop a harmonized progress towards standardized hazard testing methods for different environmental matrices.

WG2 Monitoring and sampling MPs

WG2 aims to help European and developing countries to assess and develop harmonized monitoring methods and sampling procedures for different environmental matrices. WG2 is expected to identify the needs of the participants and leveraging of existing methods and procedures. Guidelines will be established to improve scientific capabilities and help research laboratories to evaluate their procedures in line with best practices.

WG3 Instrumentation, modeling, data evaluation, software, and analytical procedures

The objectives of WG3 are to (1) understand the potential of the tools available for the analysis, (2) to help European and developing countries to assess harmonized methods, and (3) to facilitate and encourage access to EU research infrastructures and facilities. The planned activities will include the establishment of guidelines and standard operating procedures for established analytical approaches such as optical/fluorescence microscopy, vibrational spectroscopy (Fourier transform infrared and Raman spectroscopy), and thermal methods (e.g., differential scanning calorimetry or pyrolysis gas chromatography mass spectrometry). For the established techniques, special emphasis will be placed on standardized methods with a higher throughput, in order to realize a statistically relevant characterization of samples. On the other hand, novel analytical approaches having the potential to detect as well as identify plastic particles of a few μm or submicron size (NP),

preferably in its native state, will be evaluated and established. The latter will be carried out in close collaboration with WG4 to establish novel nanospectroscopic and masspetrometric approaches as a tool for this so-far predominantly uncharted field. Providing access of standardized established, as well as newly developed, innovative approaches for users across Europe and beyond, in combination with training to enable efficient use, represents another key part of work.

WG4 Nanoplastics

WG4 aims to identify suitable and validated analytical methods for detection and quantification of NPs based on the experiences of the Action participants. An additional aim is to produce/compile NP hazard and fate data, while evaluating the reliability and environmental relevance of the studies. Mechanisms of NP toxicity and interaction of NPs with biomes will be explored. Finally, analytics, metrics, and fates specific to NPs (opposed to MPs) will be evaluated and improved to more fully understand the differences among these smaller plastics in the context of global plastics pollution.

WG5 Remediation, recovery, and development of sustainable alternative to plastic materials

WG5 aims to identify reuse, recycling, recovery, and removal alternatives for environmental plastics and to define novel and sustainable technological approaches for new recycling and recovery alternatives. The ambitious challenges associated with WG5 will be reached using multidisciplinary approaches and international cooperation involving different expertise and sectors, from scientific to industrial to policymakers, participating in the Action.

WG6 Metrology and standardization

The main objectives of this WG are the validation of existing protocols for sample preparation and measurements (shape, size, abundance, and composition) in the range of N/MPs, through organization and the participation of PRIORITY laboratories in inter-laboratory studies and comparison with different independent measurement principles. Not only will different environmental conditions/ecosystems be considered, but so will the environmental samples (organisms of different size and trophic levels, soils, sediment, water, plants, etc.). Additionally, this WG will provide recommendations on best practice to make data comparable and applicable for future studies with other working groups, stakeholders, and decision-makers.

WG7 Develop new strategies to increase the synergies with society and education

This WG plans to encourage scientists to participate in science communication activities to increase awareness in society and education regarding the environmental issues related to N/MPs. As an outcome, WG7 proposes to mobilize researchers, school leaders, local authority, support staff, teachers and practitioners, students, and parents by means of traditional journalism (e.g., newspapers, radio, TV), face-to-face events (e.g., science cafes, sci-art, science centers, and museums), and online interactions (e.g., citizen science, social media, podcasts) to empower citizens as key actors in addressing N/MPs challenges.

6. Concluding Remarks

It is the opinion of the PRIORITY network that despite the large number of reports and ongoing projects, several gaps and uncertainties with regard to N/MP hazards and fate exist. In many cases, this affects the relevance, reliability, and usefulness of the data. Moreover, the lack of harmonization and standardization of sampling and analytical methods makes it difficult to compare different studies. Therefore, even basic information, such as actual exposure in environmental compartments, becomes difficult to assess with certainty. There is a consensus regarding the need to fill these knowledge gaps and to deal with the currently debated uncertainties related to N/MPs effects and exposure. Future research should be based on an identification of research needs and the coordination of

research efforts. In the end, managing and coordinating this issue will support the European Union in defining appropriate common policies to approach N/MPs issues, increasing the capability to develop risk mitigation measures.

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References

1. Plastics Europe. Plastics—The Facts 2020: An Analysis of European Plastics Production, Demand and Waste Data. Available online: <https://plasticseurope.org/knowledge-hub/plastics-the-facts-2020/> (accessed on 22 April 2022).
2. Amorim, M.J.B.; Scott-Fordsmand, J.J. Plastic pollution—A case study with *Enchytraeus crypticus*—From micro-to nanoplastics. *Environ. Pollut.* **2021**, *271*, 116363. [CrossRef] [PubMed]
3. Jambeck, J.R.; Geyer, R.; Wilcox, C.; Siegler, T.R.; Perryman, M.; Andrady, A.; Narayan, R.; Lavender Law, K. Plastic waste inputs from land into the ocean. *Science* **2015**, *347*, 768–771. [CrossRef] [PubMed]
4. Penca, J. European Plastics Strategy: What promise for global marine litter? *Mar. Policy* **2018**, *97*, 197–201. [CrossRef]
5. IUCN. Marine Plastics. Available online: <https://www.iucn.org/theme/environmental-law/our-work/oceans-and-coasts/marine-plastics> (accessed on 22 April 2022).
6. Gorrasi, G.; Sorrentino, A.; Lichtfouse, E. Back to plastic pollution in COVID times. *Environ. Chem. Lett.* **2021**, *19*, 1–4. [CrossRef] [PubMed]
7. Patrício Silva, A.L.; Tubić, A.; Vujić, M.; Soares, A.M.V.M.; Duarte, A.C.; Barcelò, D.; Rocha-Santos, T. Implications of COVID-19 pandemic on environmental compartments: Is plastic pollution a major issue? *J. Hazard. Mater. Adv.* **2022**, *5*, 100041. [CrossRef]
8. Mitrano, D.M.; Wohlleben, W. Microplastic regulation should be more precise to incentivize both innovation and environmental safety. *Nat. Commun.* **2020**, *11*, 5324. [CrossRef] [PubMed]
9. Arthur, C.; Baker, J.; Bamford, H. Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris, 9–11 September 2008; NOAA Marine Debris Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Technical Memorandum NOS-OR&R-30, January 2000. Available online: <https://marinedebris.noaa.gov/proceedings-international-research-workshop-microplastic-marine-debris> (accessed on 22 April 2022).
10. GESAMP. Sources, Fate and Effects of Microplastics in the Marine Environment: A Global Assessment; Kershaw, P.J., ed.; (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection); Rep. Stud. GESAMP 2015 No. 90, 96p. Available online: https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/pdf/GESAMP_microplastics%20full%20study.pdf (accessed on 22 April 2022).
11. Sundt, P.; Schultze, P.-E.; Syversen, F. Sources of microplastic- pollution to the marine environment. *Mepex Nor. Environ. Agency* **2014**, 1–108.
12. Hartmann, N.B.; Hüffer, T.; Thompson, R.C.; Hassellöv, M.; Verschoor, A.; Dagaard, A.E.; Rist, S.; Karlsson, T.; Brennholt, N.; Cole, M.; et al. Are We Speaking the Same Language? Recommendations for a Definition and Categorization Framework for Plastic Debris. *Environ. Sci. Technol.* **2019**, *53*, 1039–1047. [CrossRef]
13. Vethaak, A.D.; Legler, J. Microplastics and human health. *Science* **2021**, *371*, 672–674. [CrossRef]
14. Prata, J.C.; da Costa, J.P.; Lopes, I.; Duarte, A.C.; Rocha-Santos, T. Environmental exposure to microplastics: An overview on possible human health effects. *Sci. Total Environ.* **2020**, *702*, 134455. [CrossRef]
15. Scott-Fordsmand, J.J.; Navas, J.M.; Hund-Rinke, K.; Nowack, B.; Amorim, M.J.B. Nanomaterials to microplastics: Swings and roundabouts. *Nano Today* **2017**, *17*, 7–10. [CrossRef]

16. Amorim, M.J.B.; Lin, S.; Schlich, K.; Navas, J.M.; Brunelli, A.; Neubauer, N.; Vilsmeier, K.; Costa, A.L.; Gondikas, A.; Xia, T.; et al. Environmental Impacts by Fragments Released from Nanoenabled Products: A Multiassay, Multimaterial Exploration by the SUN Approach. *Environ. Sci. Technol.* **2018**, *52*, 1514–1524. [[CrossRef](#)] [[PubMed](#)]
17. GESAMP. Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean. Kershaw, P., Turra, A., Galgani, F., Eds.; (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP. 2019. Available online: <http://www.gesamp.org/publications/guidelines-for-the-monitoring-and-assessment-of-plastic-litter-in-the-ocean> (accessed on 22 April 2022).
18. Santana-Viera, S.; Montesdeoca-Esponda, S.; Guedes-Alonso, R.; Sosa-Ferrera, Z.; Santana-Rodríguez, J.J. Organic pollutants adsorbed on microplastics: Analytical methodologies and occurrence in oceans. *Trends Environ. Anal. Chem.* **2021**, *29*, e00114. [[CrossRef](#)]
19. Fu, L.; Li, J.; Wang, G.; Luan, Y.; Dai, W. Adsorption behavior of organic pollutants on microplastics. *Ecotoxicol. Environ. Saf.* **2021**, *217*, 112207. [[CrossRef](#)] [[PubMed](#)]
20. Ramsperger, A.F.R.M.; Narayana, V.K.B.; Gross, W.; Mohanraj, J.; Thelakkat, M.; Greiner, A.; Schmalz, H.; Kress, H.; Laforsch, C. Environmental exposure enhances the internalization of microplastic particles into cells. *Sci. Adv.* **2020**, *6*, eabd1211. [[CrossRef](#)]
21. Groh, K.J.; Backhaus, T.; Carney-Almroth, B.; Geueke, B.; Inostroza, P.A.; Lennquist, A.; Leslie, H.A.; Maffini, M.; Slunge, D.; Trasande, L.; et al. Overview of known plastic packaging-associated chemicals and their hazards. *Sci. Total Environ.* **2019**, *651*, 3253–3268. [[CrossRef](#)] [[PubMed](#)]
22. Manfra, L.; Marengo, V.; Libralato, G.; Costantini, M.; De Falco, F.; Cocca, M. Biodegradable polymers: A real opportunity to solve marine plastic pollution? *J. Hazard. Mater.* **2021**, *416*, 125763. [[CrossRef](#)]
23. Zheng, T.; Yuan, D.; Liu, C. Molecular toxicity of nanoplastics involving in oxidative stress and desoxyribonucleic acid damage. *J. Mol. Recognit.* **2019**, *32*, 3–9. [[CrossRef](#)]
24. Mitrano, D.M.; Wick, P.; Nowack, B. Placing nanoplastics in the context of global plastic pollution. *Nat. Nanotechnol.* **2020**, *16*, 115–147. [[CrossRef](#)]
25. Ogunola, O.S.; Onada, O.A.; Falaye, A.E. Mitigation measures to avert the impacts of plastics and microplastics in the marine environment (a review). *Environ. Sci. Pollut. Res.* **2018**, *25*, 9293–9310. [[CrossRef](#)]
26. McIlwraith, H.K.; Lin, J.; Erdle, L.M.; Mallos, N.; Diamond, M.L.; Rochman, C.M. Capturing microfibers—marketed technologies reduce microfiber emissions from washing machines. *Mar. Pollut. Bull.* **2019**, *139*, 40–45. [[CrossRef](#)] [[PubMed](#)]
27. De Falco, F.; Cocca, M.; Guarino, V.; Gentile, G.; Ambrogio, V.; Ambrosio, L.; Avella, M. Novel finishing treatments of polyamide fabrics by electrofluidodynamic process to reduce microplastic release during washings. *Polym. Degrad. Stab.* **2019**, *165*, 110–116. [[CrossRef](#)]
28. Allé, P.H.; Garcia-Muñoz, P.; Adouby, K.; Keller, N.; Robert, D. Efficient photocatalytic mineralization of polymethylmethacrylate and polystyrene nanoplastics by TiO₂/β-SiC alveolar foams. *Environ. Chem. Lett.* **2021**, *19*, 1803–1808. [[CrossRef](#)]
29. Domínguez-Jaimes, L.P.; Cedillo-González, E.I.; Luévano-Hipólito, E.; Acuña-Bedoya, J.D.; Hernández-López, J.M. Degradation of primary nanoplastics by photocatalysis using different anodized TiO₂ structures. *J. Hazard. Mater.* **2021**, *413*, 125452. [[CrossRef](#)] [[PubMed](#)]
30. Zumstein, M.T.; Schintlmeister, A.; Nelson, T.F.; Baumgartner, R.; Woebken, D.; Wagner, M.; Kohler, H.P.E.; McNeill, K.; Sander, M. Biodegradation of synthetic polymers in soils: Tracking carbon into CO₂ and microbial biomass. *Sci. Adv.* **2018**, *4*, eaas9024. [[CrossRef](#)]
31. Sun, J.; Dai, X.; Wang, Q.; van Loosdrecht, M.C.M.; Ni, B.J. Microplastics in wastewater treatment plants: Detection, occurrence and removal. *Water Res.* **2019**, *152*, 21–37. [[CrossRef](#)]
32. Ngo, P.L.; Pramanik, B.K.; Shah, K.; Roychand, R. Pathway, classification and removal efficiency of microplastics in wastewater treatment plants. *Environ. Pollut.* **2019**, *255*, 113326. [[CrossRef](#)]
33. Zhang, Y.; Jiang, H.; Bian, K.; Wang, H.; Wang, C. A critical review of control and removal strategies for microplastics from aquatic environments. *J. Environ. Chem. Eng.* **2021**, *9*, 105463. [[CrossRef](#)]
34. Mitrano, D.M.; Wagner, M. A sustainable future for plastics considering material safety and preserved value. *Nat. Rev. Mater.* **2022**, *7*, 71–73. [[CrossRef](#)]
35. Bank, M.S. (Ed.) *Microplastic in the Environment: Pattern and Process*; Springer: The Hague, The Netherlands, 2022; ISBN 978-3-030-78626-7.
36. *ISO/TR 21960:2020; Plastics—Environmental Aspects—State of Knowledge and Methodologies*; International Organization for Standardization: Geneva, Switzerland, 2020.