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Series Editors: Damià Barceló · Andrey G. Kostianoy

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Nicole Brennholt
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Plastics in the Aquatic Environment - Part II

Stakeholders' Role Against Pollution

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Founding Editor: Otto Hutzinger

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Plastics in the Aquatic Environment - Part II

Stakeholders' Role Against Pollution

Volume Editors: Friederike Stock · Georg Reifferscheid · Nicole Brennholt · Evgeniia Kostianaia

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Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last four decades, as reflected in the more than 150 volumes of *The Handbook of Environmental Chemistry*, there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry*, the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of

"pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via http://link.springer.com/bookseries/698. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Series Editors

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Introductory Remarks on the Role of Stakeholders in Addressing Plastic Pollution of the Aquatic Environment

Friederike Stock, Georg Reifferscheid, Nicole Brennholt, and Evgeniia Kostianaia

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Abstract The second volume of the book "Plastics in the Aquatic Environment – Part II: Stakeholders' Role against Pollution" assesses plastic pollution from societal and policy points of view and provides an integrated approach towards this problem. It equips the reader with regulatory pathways in place aimed at tackling this problem and provides integrated information on the opportunities and responsibilities of society and politics. The volume includes 12 chapters which give an overview of the policies proposed by various institutions such as the Baltic Marine Environment Protection Commission (HELCOM), the International Commission for the Protection of the Rhine (ICPR), the World Bank, the European Union as well as different countries across the world. The policies are evaluated regarding their progress and weaknesses. Moreover, several chapters discuss the plastic problem from a societal point of view.

Keywords Institutions, Plastic, Policies, Pollution, Society, Stakeholders

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1 Introduction

Plastics were invented at the beginning of the twentieth century. Especially from the 1950s on, the production started to increase. It raised almost exponentially and reached approximately 360 million tons in 2018 [1]. Plastics are widely used for packaging, building and construction, automotive, household, leisure and sports as well as agriculture [1]. In 2018, approximately 33% of the post-consumer plastic waste was recycled in the European Union, whereas 25% was disposed in landfills [1]. In the entire world, only 9% of plastics are recycled [2]. Inappropriate disposal of plastics leads to littering [3] and to the presence of plastics in the natural environment [4]. Of this, large parts enter the oceans via rivers [5].

Plastic waste comprises particles with heterogeneous physicochemical properties such as large size-range, different shapes, and polymer types with various additives determining their environmental fate and risk [6]. This complexity leaves several open research questions which are investigated in detail by scientists, e.g. uptake by aquatic organisms, degradation processes, sources and sinks in the environment as well as risk assessment. Answers to these questions are essential, but often too complex to be considered in regulation and management. Research about plastics started in the 1970s, mainly about marine environments [7]. Freshwater environments have been investigated only for a few years [8].

Plastics are differentiated into macro- (>5 mm) and microplastics (particles <5 mm). This term was established by Thompson et al. [4] in 2004. Microplastics comprise primary (intentionally produced plastic spherules) and secondary plastics (fragmentation of larger plastics). Once reached rivers and the sea, macroplastics might partly still be collected, whereas microplastics remain in the environment. Studies have shown that sediments are a final sink for plastics [9].

From a policy point of view, plastics and marine litter became more important in the last years. First directives on the European level were established. Among others, the Marine Strategy Framework Directive (MSFD) aims at protecting the marine environment and reaching a good environmental status by reducing marine litter and plastics. First recommendations were made for monitoring litter in the sea [10] and in rivers [11]. Standardized methods do not yet exist but the ISO/TC 61/SC 14 is working on a suggestion for standardization [12]. In 2018, the European Commission adopted a Strategy for Plastics in a Circular Economy in order to develop a circular economy.

Such multifaceted agenda of plastic pollution led to the idea of a complex book consisting of two volumes: “Plastics in the Aquatic Environment – Part I: Current Status and Challenges” and “Plastics in the Aquatic Environment – Part II: Stakeholders’ Role against Pollution.” The basis was set in July 2017 when the German Federal Institute of Hydrology (BfG) and the International Centre for Water Resources and Global Change (ICWRGC) organized a Summer School called “Plastics in Marine and Freshwater Environments” in Koblenz, Germany. The goal of this Summer School was to initiate an international network of scientists, politicians, and other environmental experts in this field, to share insights into the

current country-specific situation, to intensify information exchange between global regions, to discuss related challenges, and to enhance future collaboration opportunities. Scientists, experts of different governmental authorities, and technicians of the water and environmental sector from different countries presented the state-of-the-art in research, monitoring, and management options of micro- and macroplastics in marine and freshwater environments and discussed the plastic problem as well as possible solutions. Presentations were given by international scientists, experts from environmental and development agencies, the plastics industry, non-governmental organizations (NGOs), the World Bank, UNESCO, and the European Commission. During the Summer School, discussion rounds about awareness raising, education and capacity development, monitoring and management (regulations), impact and risk assessment as well as the industry's responsibility took place [13].

2 Overview of This Volume

The aim of this volume is to present the many efforts in science, industry, commerce, and governments to tackle the plastic problem worldwide. Voluntary trade reduction measures, alternative industrial products, school education, NGO public actions, governmental management options, and governmental regulatory actions are part of the portfolio of efforts to deal with the problem.

To solve the global plastic problem is of high urgency. Despite the discrepancy between the existing, but still incomplete scientific database and the high complexity of this issue there is demand from the public and the policy to take immediate measures (including regulatory). The book gives answers to the questions of what science, society, and politics can provide insights, what is required of science, society, politics and by whom as well as what information is needed by whom to act. The first volume "Plastics in the Aquatic Environment – Part I: Current Status and Challenges" deals with the current status and challenges with the role of environmental science. Moreover, it presents an international perspective with different examples from countries worldwide.

In the current volume, plastic pollution is assessed from societal and policy points of view. Twelve chapters provide an integrated approach towards this problem, mainly by regulatory pathways. An overview of the policies proposed by various institutions, the European Union as well as different countries (Italy, Mexico) is provided and their progress and weaknesses are evaluated. The societal perspective mainly gives insights into human perceptions and behavior, different stakeholders, and educational programs.

The chapter by Pahl et al. deals with human perceptions and behavior which determine aquatic plastic pollution [14]. The chapter is based on literature from social and environmental psychology on risk perception, risk communication, and behavior change. Pahl et al. state that aquatic plastic pollution is a consequence of human behavior. Decisions and behavior of humans throughout the life cycle of plastic result in the disposal of plastics in aquatic environments. Theories and

methods from social and behavioral sciences explain and document these processes. Plastic has a very diverse usage and is composed of different materials. Therefore, it cannot be compared to other clear-cut environmental hazards. Moreover, it is not possible to ban the entire substance which is the case for asbestos. Thus, different actions with different actors and risks. A mixture of different actions targeting different actors and risks needs to be pursued. In this context they describe the possible mechanisms of change and the determinants of decisions and behavior in detail. Furthermore, they outline media reporting, concern, and risk perception (and risk communication) with regard to plastic pollution compared to other environmental issues. Additionally, the international dimension of environmental psychology is mentioned to understand sustainable behavior change beyond western societies, which are overrepresented in most studies. This chapter concludes with the remaining challenges and research gaps. Behavioral science insights, for example, from social and environmental psychology, can ead social change processes and support the development and the evaluation f communication and behavior change interventions.

These changes of society has to be examined from individual behavior to communities and bigger groups. Approaches, however, involves social identities, social norms, and other predictors of behavior change,going beyond an information/education focus.

Sandu et al. [15] present the role of society for reducing plastic pollution. The authors describe the multitude of problems with plastics present in the environment and show how a shift of attitude could be attained as well as how education and science may contribute to change this global problem. Researchers, on the one hand, present state-of-the-art of plastic contamination and study effects. On the other hand, many research questions such as degradation, impacts, and risk assessment remain open. Sandu et al. [15] point out that education is one of the key aspects for reducing the plastic pollution. This can be achieved by educational programs such as classrooms and outdoor experiences, field trainings, cleaning actions, or citizen science campaigns. Further examples are an education program about Ocean Literacy, a plastic school project or massive open online courses on marine litter. Apart from education, the authors present innovative tools such as monitoring programs for observing macro- or microplastic with remote observation systems (projects such as RIMMEL or SPlasH!) and ideas to design environmentally friendlier substitutes of toxic plastic compounds as well as the creation of new materials. Moreover, the plastic industry started to reuse plastics in new products or to de-polymerize plastics to monomers. Several recommendations are mentioned how the plastic industry could contribute to further reduce pollution. The last aspect in the book chapter deals with the role of NGOs who play a major role to connect stakeholders, initiate projects and actions (e.g. 5 Gyres, the Ocean Cleanup, Clear Blue Sea, Waste Free Oceans, Waste Free Waters) and the rising of awareness.

Mironenko and Mironenko present different educational programs worldwide for addressing plastic pollution [16]. In their chapter, the authors differentiate between formal (compulsory education) and non-formal (outside the formal education system) education. Many formal educational programs in primary and secondary

educational levels such as outdoor classes, board games, or beach clean-ups, about waste, water, and energy for teaching sustainability exist worldwide. Some governmental educational initiatives such as project weeks at schools or programs that attest schools to be environmentally friendly and sustainable were also launched in the last years. In universities, plastic pollution is integrated in seminars and lectures in different curricula, plastic-related research is conducted, and green campus programs were created. Non-formal educational programs are less formalized and interactive and thus important for a change of perceptions and behavior. They include open access Massive Open Online Courses which run on a web platform, are free of cost and open for all interested participants. Courses about marine litter were created for the first time in 2015 and have also been introduced in many universities worldwide. Moreover, other open access training opportunities such as Educational Packs (4 weeks online training) exist. Other non-formal educational programs are sustainability games (mostly for primary and secondary schools) and mobile exhibitions for awareness raising. The authors conclude that a gap in waste education still exists and that despite these many programs, only few of them are included in the educational program, often rely on external stakeholders, and usually lack governmental support.

The chapter by Kicošev and Galambos deals with a stakeholder analysis of plastics in protected areas along the Danube River in Serbia [17]. The research was conducted with a field survey on plastic accumulation and a stakeholder survey with questionnaires with visitors (domestic and international) of the protected areas. The questionnaire included valuation of the ecosystem services, estimation of threats, analysis of awareness about microplastic pollution and its impacts, importance of the preservation of the ecosystem services, and the valuation of the natural environment by paying a certain fee. The answers differed depending on the five different groups of participants (domestic or foreign visitors; participants with different monthly income; employees from water management companies; journalists; the ones who attended the education program). However, mostly everybody agreed that plastic pollution is a significant problem. The majority was willing to pay for the preservation of an unpolluted natural environment. Thus, the authors conclude that a financial contribution would be a high benefit for better preserving the natural environment and improving the quality of the ecosystem.

Gionfra et al. from the Institute for European Environmental Policy discuss the role of policy in tackling plastic waste in the aquatic environment [18]. They address EU legislations and describe different policy instruments: regulations, market-based instruments, financing and investment as well as information tools and voluntary schemes. At the European level, several actions and plans have been initiated in the last years (EU Circular Economy Action Plan, waste directives and the EU Strategy for Plastics, Directive on Single-use plastics) for – among others – reaching a higher recycling rate, reusing plastics, or reducing landfills. Regulation actions have been implemented in some countries with a ban on certain products (Italy's ban on cotton buds, France's ban on single-use plastic plates, cups, and cutlery, microplastics in cosmetics). Market-based instruments include taxes and fees (e.g. plastic packaging tax, UK) and the Extended Producer Responsibility (e.g. modulation of fees, CONAI, Italy). Financing and investments are crucial for research and innovation,

waste management infrastructure, or Green Public Procurement (public budgets). Voluntary commitments include, e.g. a 100% recycling rate of products (IKEA) and are supported by political actions and support. Moreover, the authors mention information tools for facilitating the flow of information regarding plastics (e.g. app AskREACH).

In their chapter González-Fernández and Hanke introduce monitoring approaches for marine litter in the European Sea basins including the Mediterranean Sea, Black Sea, Baltic Sea, and the North-East Atlantic region with the North Sea [19]. As many countries share semi-enclosed sea basins, overlapping transnational frameworks were initiated for protecting the marine environment. For better haromonizing methods, estimating marine litter and not doubling monitoring activities, cooperation initiatives have been initiated. In the next years, monitoring approaches should be developed and implemented all over Europe and via international cooperation in order to improve harmonization and comparability of data for marine litter and plastic pollution. In order to attain this objective and to guarantee an effective monitoring with common monitoring elements, its implementation takes place under the umbrella of the European Marine Strategy Framework Directive (MSFD; Descriptor 10: Marine Litter) and the four related Regional Sea Conventions: OSPAR Commission, HELCOM, Black Sea Commission, and UNEP/MAP Barcelona Convention. These Regional Sea Conventions and the MSFD are extensively described in this chapter as well as the marine litter monitoring elements on the coastline/beach, in the surface layer of the water column, on the seabed, and in biota differentiated according to micro-, meso- and macrosized litter.

Hohenblum and Meier from the Austrian Environment Agency and the German Environment Agency describe possibilities to act as a public entity in advance of legislative measures [20]. The Austrian Environment Agency was a key driver in Europe to initiate studies evaluating the microplastic pollution of freshwater environments and to suggest how sources can be reduced. The results of these studies with a focus on the Danube River stimulated enormously scientific, social, and political activities. As a first consequence of the proof that rivers in Europe are considerably polluted with primary microplastics, a 10-point action plan was agreed with stakeholders along the production chain to avoid the emission of plastic pellets. Hohenblum and Meier also describe activities of the interdisciplinary Interest Group Plastics (IG Plastics) under the umbrella of the Network of Heads of Environmental Agencies (EPA Network). The mandate of the group is to identify relevant policy fields and to address the most efficient measures to combat the environmental plastic problem. The IG Plastics supported the European Commission prior to the publication of the EU Plastics Strategy by describing the main topics that need to be reflected to reduce or prevent not wanted plastic entries into the environment.

In their chapter Stötter and Schulte-Wülwer-Leidig [21] describe the tasks of a river basin commission by the example of the ICPR, the International Commission for the protection of the Rhine. In the ICPR, nine states in the river basin and the European Commission cooperate in order to harmonize the interests of use and protection in the Rhine basin. Following the founding of the ICPR in 1999 among other objectives, the preservation, improvement, and sustainable development of the

Rhine ecosystem were central elements of the Commission's activities. Considering the fact that the Rhine was known as the sewer of Europe, affected by several disasters like the so-called Sandoz catastrophe in 1986 or centennial floods, the Commission can look back at a long and successful history being an important international networker to set up programs that helped to improve the situation of the Rhine. Now, plastics in rivers is an upcoming topic for river commissions. In this context, the ICPR sees its main task in collecting information and in information exchange about research projects, workshops, conferences, and other initiatives in the countries of the Rhine catchment and among IGOs and NGOs. According to Stötter and Schulte-Wülwer-Leidig, the basis for regular monitoring of plastics is – among others – a set of harmonized analytical methods and conceptual sampling, measuring, and reporting concepts, which is presently part of research. Furthermore, a reduction of plastics at the source should take place. Thus, water management is not responsible in the first place.

The chapter "Five years since the 2013 HELCOM Ministerial Declaration" by Ruiz and Stankiewicz [22] aims at analyzing what has happened in these years since the HELCOM's (Helsinki Commission – Baltic Marine Environment Protection Commission) official starting point on the topic of marine litter (including plastic). This chapter focuses in particular on i) if appropriate monitoring programs exist for the aquatic environments, ii) if enough monitoring data for evaluating trends are present, iii) if the main sources of marine litter to the Baltic Sea are known and iv) if regional actions in the HELCOM Regional Action Plan on Marine Litter (2015) are in place which address these sources. HELCOM is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area. Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia, and Sweden are contracting parties. The main goal was to protect the marine environment from input of pollutants via intergovernmental cooperation. Besides the HELCOM commitments on marine litter, marine litter monitoring, assessment of marine litter in the Baltic Sea, and implementing the Regional Action Plan on Marine Litter, HELCOM's role outside the Baltic Sea region is described in this chapter with regard to the United Nations, other European Regional Sea Conventions, and the European Union. Furthermore, a perspective will be provided when the Baltic Sea Action Plan (BSAP): which was signed in 2007 will be updated in 2021. The main goal was to achieve a good environmental status of the Baltic Sea. In order to meet HELCOM's strategic goals and ecological objectives as well as marine and water targets of the 2030 UN Agenda for Sustainable Development, the latest research results will be integrated in the BSAP in 2021.

Caspary [23], former Relationship Manager with the International Finance Cooperation at the World Bank, writes about the role of finance and technical assistance by Development Finance Institutions (DFI) for combating the marine plastic pollution. DFIs have great expertise by supporting developing and emerging countries with development challenges. However, according to Caspary [23], there are still many challenges for DFIs regarding the effectiveness of the marine plastics agenda

as these programs are only implemented if the issue area is priorised by the partner country. Another fundamental prerequisite is integration with other key development issues, for instance, with innovative solid waste management approaches such as community-based recycling (while creating jobs) and/or health risks issues like blocking storm sanitary sewers. In his chapter Caspary gives a short description of what DFIs are and what they do. He describes the multilateral work on marine plastics in sovereign finance and technical assistance and the DFIs' support for private efforts. According to Caspary, In order to prevent and reduce marine plastic litter, DFIs will most probably incorporate mainstreaming of efforts in and among as well as collaborative approaches among the DFIs and collaborate with other institutions.

Two chapters deal with national legislations. Lara et al. [24] focus on the current legislative framework on plastic pollution in Mexico and propose a future framework for a national legislative approach in Mexico. The authors first give an overview about the legal structures concerning the environment. Besides mentioning of a healthy environment in the Constitution, Mexico participates in conventions regarding ocean pollution. In the Federal legislation, plastics are mostly indirectly included in different laws concerning, for example, waste, water, dumping, and the ocean. Moreover, official norms and voluntary guidelines exist and first state legislation laws were enacted in Mexico City to reuse plastic bags and reduce plastic straws. For the future, the authors suggest to ban unnecessary and problematic (hazardous, not recyclable) plastics, to replace plastics when an alternative exists, and to define necessary plastics by national legislation. Furthermore, plastics should be considered as a resource to be reused.

Campanale et al. [25] have a critical look at the problem of microplastics and regulatory strategies in Italy. They give an overview of the legislation and regulation about plastic in Europe before the authors focus on the Italian regulation. There are several European directives and international conventions. Italy has furthermore implemented other instruments for combating plastic pollution. As one of the first countries, Italy committed on protecting its aquatic environments from pollution including plastics. The results of different studies show that appropriate methods and the analysis of microplastics are crucial for monitoring. Sampling, extraction from evironmental matrices and analysis is challenging, especially due to the small size of microplastics. For monitoring microplastics in freshwater environments this chapter describes roughly the major issues and gives a short overview of methodological approaches. For freshwater environments, methodologies for monitoring and sampling does not yet exist. Therefore, the Regional Agencies for Environmental Protection (ARPA) which include the delegation and commission of the Italian Regions, conducted different monitorings of microplastics in the Italian Seas. It was part of national activities for replying to a request by the MSFD regarding plastics. This monitoring was fincanced by the Italien Ministry of the Environment and Protection of the Territory and the Sea (MATTM). Hereinafter, Campanale et al. [25] present the MICROPLASMA (MIcro and maCRO PLAStic pollution

Monitoring with Advanced technologies) project in detail, especially the methodological approach. MICROPLASMA is a preliminary monitoring study of microplastics in the Ofanto, the biggest river of Apulia Region (Southern Italy). The aim of this study is to enlarge the data about the pollution with microplastics in Italy as well as to broaden the knowledge about distribution, behavior and impact for future regulations.

3 Discussion

In order to tackle the plastic pollution problem, it is essential not only to continue research on the scientific methods of detection, analysis, removal of plastics from the aquatic environments, but also to develop policy instruments, raise public awareness, study citizens' behavior, and attitude towards this issue.

Literature review also shows that there has been an increasing interest towards this aspect of research on plastics. Springer has also published several books on the topic of plastic pollution, which gradually developed from being just a part in books on marine litter to separate books dedicated to this issue. For example, in 2015, in the book "Marine Anthropogenic Litter" (eds. Melanie Bergmann, Lars Gutow, Michael Klages) [26], two parts were dedicated to marine litter in general (abiotic aspects of marine litter pollution and biological implications of marine litter). The third part was focused on microplastics, its sources, consequences, solutions, methodologies used for detection and identification of microplastics. The fourth part discussed socio-economic implications of marine anthropogenic litter, including aspects affecting human health, economic impacts of marine litter, regulation and management mechanisms, and the role of citizen science in marine litter monitoring. The book "Freshwater Microplastics. Emerging Environmental Contaminants?" (eds. Martin Wagner, Scott Lambert) [8], published in 2018, discussed the problem of microplastics in all its complexity, from sources, transport, and fate of microplastics to socio-economic aspects such as citizen science and stakeholder involvement, social-ecological risk perspective, regulation and management challenges, and potential solutions. In 2019, a narrowly focused book was published – "Bioremediation Technology for Plastic Waste" (eds. Mohd Shahnawaz, Manisha Sangale, Avinash Ade) [27], which also discussed such social aspects as social awareness of plastic waste threat and policy and legislation of plastic waste. Most recently, in 2020, the book "Microplastics in Terrestrial Environments – Emerging Contaminants and Major Challenges" (eds. Defu He, Yongming Luo) [28] dedicated a part of it to health risks of microplastics and control approaches. As we see from these examples, chapters on management and regulation of plastic waste, the role of citizen science and overall socio-economic aspects of the problem are continuously included in the publications on this matter.

It is evident that more and more research is dedicated to socio-economic aspects of the plastic pollution problem. Acknowledging the importance of the role of the society and policy mechanisms in combatting the plastic pollution problem, we also

found it important to dedicate this whole volume to these aspects. It is helpful to see chapters on various regulation and management mechanisms, financial instruments, educational tools and programs, the role of society at large, all gathered in one book volume. The chapters present a multitude of actions by different stakeholders from a societal point of view. Moreover, as the first directives and laws have been initiated in the last years regarding marine litter and plastics, this volume also presents some policies and regulatory strategies.

The severity of the plastic pollution problem is different across the world, as well as the state of science development or technical and innovation capacity. However, analyzing such various aspects of this problem and discussing case studies from various parts of the world can certainly broaden our perspective and provide insights as to what can be done, what measures and mechanisms work, and which ones do not work and surely give a better understanding of the problem and available solutions as a whole.

We hope that this volume will be useful for policy-makers, professionals working in the education field, NGOs, and anyone else interested in this topic. Together with the other volume on this topic, "Plastics in the Aquatic Environment" – "Part I: Current Status and Challenges," we are positive that this volume will serve as a useful tool to make the aquatic environments all over the world cleaner and healthier.

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Human Perceptions and Behaviour Determine Aquatic Plastic Pollution

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Abstract Aquatic plastic pollution is entirely due to humans. Throughout the whole life cycle of plastic, from production via consumption to disposal, it is human decisions and behaviour that ultimately lead to plastic ending up in aquatic environments. Every sector, every individual plays a role in the fate of plastic waste. For example, designers and producers make decisions about materials, appearance and functionality; consumers make purchasing decisions and dispose of items after use; policy makers decide on regulation and legal frameworks. These processes can be documented and explained using theories and methods from the social and behavioural sciences. More importantly, these insights can guide social change processes systematically and help develop and evaluate effective communication and behaviour change interventions. This chapter will summarise recent work on the human dimension in aquatic plastic pollution. Our focus will be on relevant literature from social and environmental psychology on risk perception, risk communication and behaviour change. We will draw on interdisciplinary and international work to highlight challenges to such integrative research and misunderstandings between disciplines. We will include research on macro- and microplastics and a range of stakeholders such as fishermen, the general public and young people. This will be complemented by a selective review of research on littering, media coverage and international initiatives. Finally, we will summarise remaining challenges and outline gaps in research.

Keywords Attitudes, Emotions, Psychology, Social norms

1 Plastic Pollution and the Human Dimension: Introduction

Plastic pollution is an entirely anthropogenic problem; it is solely caused by people who produce plastic materials and by people's use and disposal of these materials in a vast range of societal contexts [1]. Plastic materials have only been in use widely since the 1960s, motivated by many benefits to society, e.g. in healthcare, hygiene, due to their light weight, durability and low cost. Given this relatively short time span, the amount of plastic in the environment and the trends for both production and escape into the natural environment at the global level [2] are staggering. Consequences of plastic in the environment have been widely documented, especially in terms of wildlife and economic impacts [3, 4] (and see overview in [5]), and the issue has attracted sustained attention in national and international policy (e.g. UN, G7, G20, EU). Emerging issues include micro- and nano-plastics (e.g. [6]) and suspected human health concerns (e.g. [7]). Research has to date largely focused on coastal and marine environmental zones, but other compartments are being investigated now, including freshwater, soil and even air (for microplastics). The present chapter explores the role of social and environmental psychology for understanding and reducing the flow of plastic to aquatic environments. We will discuss conceptual and

practical aspects of selected research and identify progress as well as gaps for research in a fast-moving field. This is not an exhaustive review, and we will draw on research targeting wider environmental challenges where this serves to highlight a gap or potential for research.

2 Plastic as a System and the Role of Human Decisions and Behaviours

Plastic pollution in the environment, whether it is macro-, micro or nano-plastics, results from a system of interlinking social, technical, economic and natural processes (Fig. 1, Section 1). There is no single source or pathway that determines the type and amount of material ending up in the natural environment. The flow of plastic is determined by individuals, communities, companies and policy makers, to name but a few of the actors within the social-environmental system [1, 6]. These actors have varying perceptions, goals, values and opportunities that determine their practices and behaviours. For example, a technology manufacturer might decide to use plastic packaging because it is durable, cheap and protects against moisture. A cosmetics company might decide to replace traditional natural ingredients with plastic microbeads to save money and reduce allergens in their products. Some consumers will be indifferent to these practices; some consumers might support these motives and decisions, whereas others might dislike and avoid products because of the plastic content. Policy makers make decisions on rules that apply to the system, and other actors might lobby for or against such rules. The media influence the system by their reporting, e.g. on plastic impacts on wildlife, which can trigger concern in the general public. Such wildlife concern has, in turn, been linked to action, for example, by increasing engagement in beach cleans (e.g. https://www.keepbritaintidy.org/news/new-research-reveals-power-blue-planet-ii, and see section on mechanism of change below).

To reiterate, plastic pollution is the consequence of decisions and actions taken at individual and aggregate levels in the overall system, at least until plastics escape into the environment. Once escaped, interactions between natural processes such as abrasion, wind, water dynamics and human actions such as clean-ups determine the ultimate fate of the material (Fig. 1, Section 1). Psychology as a discipline is defined as the science of human mind and behaviour (https://dictionary.apa.org/psychology). It is our contention that considering the psychological principles underlying human decisions and behaviour and social dynamics will help us design better, more effective and sustainable systems, policies and other mechanisms of change that can stem the leakage of plastic.

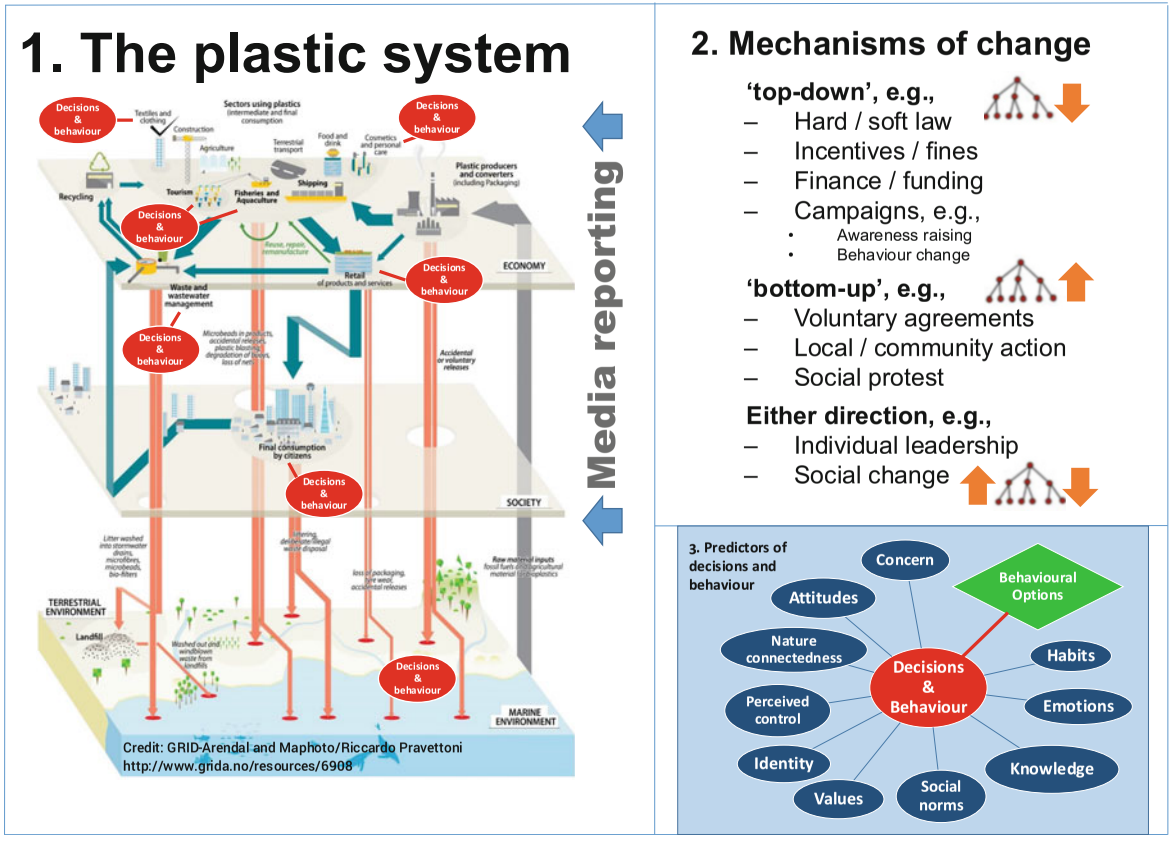

Fig. 1 The plastic system (Section 1), possible mechanisms of change (Section 2) and determinants of decisions and behaviour (Section 3). Original graphic in Section 1 adapted from GRID-Arendal and Maphoto/Ricardo Pravettoni with decision/behaviour bubbles added for illustration

3 Mechanisms of Change

While complex systems dependent on many different actors might seem difficult to change, at the same time, they pose a range of opportunities. Plastic pollution is different from other more clear-cut environmental hazards because of its multitude of uses and wide range of materials. Plastic is not one substance used in a limited range of contexts that can be addressed by a single ban (e.g. such as seen for asbestos). Rather, a mixture of different actions targeting different actors and risks needs to be pursued (e.g. [8, 9]; Fig. 1, Section 2).

Top-down actions such as new regulations and laws set the practical and legal context for change. Laws, bans and restrictions are powerful tools partly because they signal a social norm of undesirable behaviour. Sunstein calls this the 'expressive function of law' [10] (chapter "The Expressive Function of Law"). By the same token, these tools may fall short of their potential if there is no buy-in from people on the ground, for example, if the change is not prepared carefully or conflicts with consumer practices. Media outlets have reported backlash from consumers against plastic bag charges in Australia in 2018 and in the USA in 2020 [11, 12]. Alpizar et al. [13] review evidence that combining charges with public engagement campaigns has been more successful than introducing charges by themselves. Enforcement is costly and can be difficult when there is reluctance to change, as it was reported for India [14]. Financial incentives and fines can be useful top-down tools but rely on extrinsic motivation (e.g. taking your own carrier bags to the supermarket to save some money on what would be 5p on each new bag). These types of top-down actions may be limited from a psychological point of view. As the extrinsic motivation is only associated with that particular incentive or fine, it is unlikely to change core attitudes and thereby spill over to other behaviours (e.g. people may take reusable bags to the supermarket to save money, but if a similar incentive is not in place for other products like reusing bottles, or coffee cups, then these behaviours are unlikely to be altered), and the behaviour can be short-lived and only prevails as long as the incentive exists. Other evidence suggests that financial motives may not be as strong as once thought and moral motivation can be a stronger driver of environmental behaviour [15]. Benartzi et al. [16] provide evidence for behaviour change interventions being more cost-effective than financial incentive programmes. Having said that, of course price-based instruments will remain important when looking at the overall mix of change methods, but here we focus on the psychological processes of change. Going beyond the consumer level, financial investment also supports the development of new materials and processes, but such technical development may falter if it does not take into account people's preferences and lifestyle. For example, new technology that helps 'clean up' the environment, processes that make use of recovered and recycled materials from the environment, or new materials marketed as degradable may further engrain a throw-away culture, thus not addressing all aspects of the original problem (wasting resources, using virgin materials, having items enter and impact the environment).

Successful top-down change can be observed in the absence of direct regulation change where individual leadership triggers change, for example, because of personal concern over plastic pollution, and sometimes in the face of opposition and reluctance. For example, supermarket chain Iceland's boss Richard Walker has been described as an environmentalist and is also a trustee of the environmental charity Surfers against Sewage. The retailer announced plans in 2018 to go plastic-free on own labels within 5 years [17]. Other UK retailers such as Waitrose and Marks & Spencer have run voluntary trial schemes, for example, for plastic bag charges or unpackaged produce, to inform changes ahead of potential new laws [18]. Centrally organised campaigns have communicated the adverse effects of plastic pollution and have targeted behaviour change (e.g. https://rethinkplasticalliance.eu/campaign/). We refer to these as 'top-down' actions because they are organised at a superordinate level, e.g. the top of an organisation, a national or global set of principles.

Bottom-up pressures are also key to triggering change. In fact, it could be argued that none of the above mechanisms would be enacted without action from the ground up by individuals and communities that signal a desire for change. For example, a single individual (Rebecca Hoskins), motivated by seeing the damage plastic bags were causing wildlife, started a campaign in a small English town to ban the plastic bag in 2007 [19]. Indian fishermen, observing large amounts of plastic litter, have gone through their regional union to approach the Fisheries ministry for help in setting up a recovery and recycling facility that provides work to local women (https://www.nationalgeographic.co.uk/environment-and-conservation/2018/05/how-indias-fishermen-turn-ocean-plastic-roads). A mobile phone application initiated in the Netherlands, Beat the Microbead, has raised the profile of microplastics in cosmetic products and contributed to the start of legal and commercial changes in the use of these materials (reported in [20]).

One important process of change is the transformation of behaviours based on social dynamics. Actual and perceived rates of behaviour performed and accepted by the majority of the society are viewed as a vehicle for change [21]. For example, the visible extent of litter on the street, as well as the direct observation of other people littering, influences people's waste management and eventually forms new social norms [22, 23]. Under specific circumstances, single, charismatic figures or minorities can push social change as well from the bottom-up [24, 25], as with the Swedish activist Greta Thunberg for climate change, for example. For minorities or individuals to gain influence, it is key to be consistent and united in their argument [26], credible, flexible and compromising in their discussion style [27] and to appear as a sub-group of the majority instead of an outgroup [28]. New shared identities can emerge from group membership and social interaction in order to solve a perceived discrepancy between the way the world is and the way the world is desired to be [29].

There are many more examples for both top-down and bottom-up processes, and, in fact, the distinction is not always clear. It seems things can change quickly and last for the long run if both processes come together, combining, for example, policy change and NGO (non-governmental organisations) campaigns with self-organised community activities and individual leadership (Fig. 1, Section 2). Change that is

triggered from different directions in response to concern and agreement between different actors might well be the most powerful and long-lasting.

However, as the summary above indicates, evidence is often rather anecdotal, presented in the media or on corporate websites, rather than independently and systematically assessed. Best practice collections exist and are an excellent starting point (e.g. http://www.marlisco.eu/best-practice-guide.en.html) but further analysis needs to untangle 'what works' and distil the mechanisms and also potential pitfalls [6]. In research terms, we need to apply interdisciplinary perspectives to both the issue itself and to potential solutions. We need to understand the perceptions, motivations and intentions of different stakeholders to design solutions and alternative systems that will be acceptable and effective. These candidate solutions then require systematic small-scale trials and evaluation to avoid unwanted side effects (e.g. increased carbon footprint) before they are rolled out more widely. Such evidence-based approaches require social and behavioural science methods (see Box 1; [1]), alongside economic, technical and lifecycle analyses and environmental science assessments of risk and harm.

Box 1 Methods in the Social and Behavioural Sciences: A Quick Primer

With a focus on human decisions and behaviour as the subject of study, social and environmental psychology applies a wide range of analytical approaches from qualitative to quantitative methods. Qualitative research is often used for hypothesis development and to gain deeper, detailed insights into novel questions. Qualitative research can also be used to explore spontaneous responses to examples of plastic content in everyday consumer items [30], responses to a specific task such as picking up and recording plastic litter [31], or in the form of walking interviews to explore participants' meaning and understanding of place [32]. Typical methods comprise face-to-face interviews, open-ended survey questions or focus groups [33]. Troschinetz and Mihelcic [34] present a qualitative analysis of case studies on recycling and solid waste generation in developing nations. Qualitative methods involve thematic analysis of statements and result in textual summaries, whereas quantitative methods deal with numerical scores.

The sample sizes in quantitative research are larger to enable statistical analyses, and, where possible, researchers use samples representative of the target population (e.g. Eurobarometer). Quantitative methods tend to be used in two ways. First, they can describe the attitudes, perceptions and behaviours of certain populations (e.g. [35]), or they can describe the relationships between these, for example, to understand which factors are most important for key outcomes (e.g. [36]. Second, they can test the effects of interventions, ideally within an experimental design including randomisation and control groups. For example, an intervention can be tested in terms of behaviour

(continued)

Box 1 (continued)
change over time and in comparison to an alternative intervention or the status quo.

Quantitative social research typically gathers information on individual behaviour and the drivers behind that behaviour via social surveys with standardised questions and response scales, constructed according to best practice questionnaire design [37]. While able to directly tap into the relevant behaviours and drivers, self-report measures can be affected by issues such as memory bias and desirability bias (where participants may misremember or want to look good). Measures of behavioural intentions need to be interpreted cautiously because of the intention-behaviour gap (e.g. [38]). However, there is evidence to support self-report measures. Kormos and Gifford [39] ran a meta-analysis of 15 studies that demonstrated a positive and nominally large effect size of $r = 0.46$ for the association between self-reported and objective behaviour. So, while self-report data has limitations (as does any specific research method), on balance it is a reasonable method for gaining quick and affordable insights into human perceptions and behaviour.

Quantitative analysis of existing secondary data sets offers additional opportunities for large-scale research on decisions and behaviours (e.g. [40]), as does so-called big data from social media or purchasing decisions. In addition to social surveys, observation studies can measure behaviour with rigorous sampling and observation procedures (e.g. [41, 42]). While observations can monitor behaviour directly, they cannot easily derive the motivations and beliefs underlying the observed behaviour (so cannot shed light on why a person has acted the way they have).

To maximise the quality of data, survey design should be undertaken by social science experts, who will, for example, ensure questions and response scales are balanced and neutral to minimise bias. Recent work using self-report to measure behaviour has asked about the previous week specifically, in order to minimise memory bias, and has included examples of both negative and positive behaviours [43]. Another recommendation is to combine data from different sources such as interviews, survey data and observations, a so called triangulation of methods. Research questions and methods should ideally be developed based on the existing literature and within interdisciplinary teams to avoid ‘re-inventing the wheel’ and allow for integrative analysis of the social data and environmental data collected by other scientists. This will help build a solid evidence base for comprehensive, feasible, acceptable and sustainable solutions that reduce plastic pollution.

For efforts to be successful in reducing plastic pollution, it is important to integrate a range of established social science research methods to consider: (1) the product and how it is used, (2) the context it is used in and where and when it might leak into the environment, and (3) the actors and their decisions and

behaviours that underlie this plastic use and leakage. Understanding and integrating this human dimension systematically will improve the success of actions taken and help combine top-down approaches such as legal frameworks and financial incentives with bottom-up approaches such as voluntary agreements and community or grassroots activities. In the remainder of this chapter, we will review the role of behaviour and behaviour change specifically, followed by a summary of risk perception and communication.

4 Behaviour

4.1 Predictors of Behaviour

Talking to people outside the environmental psychology field, we often hear that 'all we need to do is tell people the facts' or 'tell them how bad it is'. While factual knowledge is of course important and has to underpin any efforts to change behaviour, plenty of evidence shows that increasing knowledge is not the key factor for changing behaviour [44, 45]. To illustrate, most people have an understanding of healthy lifestyles, but few eat very healthily and take regular exercise. Moreover, if messages are too negative and raise fear, this can also undermine action, because people may start to avoid averse messages [46].

A range of factors other than factual knowledge have been shown to be important predictors of behaviour whenever behavioural options are available that offer choice (see [1, 47] for overviews, and Fig. 1, Section 3). Being concerned about a problem is generally (but not always) positively correlated with pro-environmental behaviour, as are positive attitudes about the target behaviour. For example, people who think positively about reusable water bottles will be more likely to use them. Nature connectedness, and, more recently, ocean connectedness (a subjective feeling of being part of nature/the ocean), has been found to be associated with pro-environmental behaviour (e.g. [40, 48]). A sense of efficacy or control over actions, and social norms, is among the most important predictors of behaviour [22, 23]. Someone who feels their actions will make a difference (perceived control) is more likely to change their behaviour, compared to someone who feels powerless. What other people do or are thought to be doing is a crucial determinant of behaviour, even if people do not recognise this as influential [49]. For example, when looking at the drivers of plastic use and disposal in Norway, concern and knowledge about plastic waste were not related to individual behaviour, but, instead, the more influential predictors of behaviour were people's own attitudes towards marine litter, what they felt others thought of the issue and if they had a sense of behavioural control or ability to act and contribute to the solution [50]. Emotions, values and social identity can also help or hinder action above and beyond the presence of knowledge [51].

It is now generally recognised that there are two types of decision-making, fast and slow [52]. Fast, or automatic, thinking is determined by emotion and cognitive

shortcuts whereas slow, or controlled, thinking is determined by careful consideration and analysis of information. In everyday life, people have little opportunity (and sometimes inclination) to gather comprehensive facts before they act, so behaviour follows more automatic cues such as emotion. For example, feeling upset at seeing turtles being caught in plastic netting might directly motivate joining an anti-plastic campaign. If someone places great value in the natural world (biospheric values, [53]), this might motivate them to join a beach clean. A pro-environmental self-identity (seeing oneself as the sort of person that protects nature) is also positively linked to pro-environmental action. Heidbreder et al. [54] reviewed literature on perceptions, behaviours and interventions regarding plastic pollution, which includes data on problem awareness, the link between plastic pollution and human health and wellbeing, as well as consumer perceptions of products and materials. In line with above, the authors conclude that problem awareness and knowledge alone do not closely connect to behaviour change. Instead, they identify habits and social factors as main predictors of plastic-related behaviours.

In addition, context factors, which give people the opportunity to act, are very important [55], such as the accessibility and design of the waste disposal system, as well as availability of alternative materials. For example, if there is no recycling bin nearby, it takes someone to have very strong pro-recycling attitudes to persist in finding one. Varotto and Spagnolli [56] ran a meta-analysis of 70 recycling interventions and found that environmental alterations, next to social modelling, were the most effective approaches. Geiger et al. [57] stress that both individual and contextual factors work together. Future activities should go beyond solely communicating facts and targeting knowledge to apply more comprehensive models of behaviour change and community engagement.

4.2 Quantifying Behaviour

Behavioural practices can contribute to pollution, but behaviour quantification (e.g. the frequencies of different behaviours and how these link to environmental impacts) is lacking, especially at scales that meaningfully correspond with analysis in other disciplines such as national or even global plastic flows ([2] for the global level, [58] for Austria). One of the few papers that provides objective data on littering behaviour and also emphasises the role of structural factors is by Schultz et al. [42]. These authors obtained data in more than 100 outdoor locations such as city centres and service stations, by observing nearly 10,000 individuals in 10 US states. Using covert observation by pairs of trained researchers, they focused on littering behaviour. They found a general littering rate of 17% if people had something to dispose of while visiting the site and 65% improper disposal for cigarette butts (mostly dropping with intent, flicking or stomping). For general littering, Schultz et al. [42] found that littering behaviour was more frequent when the person was younger and male, when fewer bins were available and when bins

were further away and when there was other waste lying around. This study is a rare example of research that quantifies human behaviour, in this case littering. Clearly, behaviour is important for reducing littering and by implication for reducing plastic pollution. In the following section, we will review some examples of behaviour change activities.

4.3 Behaviour Change Interventions

Ohtomo and Ohnuma [59] used voice prompts to reduce the use of disposable plastic bags in Japanese supermarkets applying a dual process model that distinguishes automatic from controlled behaviour. Instead of handing out the bags automatically, customers were asked if they really would like a disposable plastic bag and had to confirm this with 'yes'. This led to a significant decline in plastic bag use. Gupta [14] attempted to increase compliance with the plastic bag ban, which was introduced in India in 2009, but not entirely successful (94% still preferred single-use plastic bags). The intervention involved the provision of information, a financial incentive and offering alternatives to plastic bags. This led to a significant increase in people bringing their own bag and a decrease of favourable intentions to use single-use plastic bags. This indicates that a plastic ban alone or financial disincentives do not automatically bring about change but that psychological factors need to be considered, in line with the discussion above.

Rivers, Shenstone-Harris [60] interpreted a new plastic bag levy in Canada as a nudge to reduce plastic bag use. They found that the levy only decreased single-use plastic bag use among people with high economic status and people who already used alternatives (a strengthening of their existing norms). Other population groups remained unaffected especially low income groups. In the UK, a small single-use plastic bag charge was found to significantly reduce the number of disposable carrier bags taken from supermarkets; however when looking at multiple plastic-related behaviours, this was not found to influence behaviours in other contexts or other behaviours [61], as would be expected from extrinsic motivation.

O'Connor et al. [55] assessed how the design, number and proximity of bins influenced recycling behaviour of plastic bottles in schools in Texas. They found that only placing the bins directly in the classrooms, and thereby reducing the distance to the bin, drastically increased the number of plastic bottles recycled correctly. Design and number of bins did not have an effect.

Dorn and Stöckli [62] assessed the effect of social norms on sustainable decision-making in the context of takeaway boxes during lunchbreaks in Switzerland. They found that a social norm message did not have significant effects, whereas being observed by someone who previously made a sustainable choice significantly increased the likelihood of people choosing the reusable takeaway lunchbox. Lawman et al. [63] investigated how the installation of water fountains, the distribution of reusable water bottles and the provision of knowledge affected the consumption of water and the use of reusable bottles in Philadelphia, USA. They

found an increase of water consumption and bottle use of the combination of these measures. In the UK, Poortinga and Whitaker [64] assessed the effect of environmental messaging, the provision of alternatives as well as financial charges and incentives on the use of reusable coffee cups. They found an effect for all interventions separately, except the discount on reusable cups. They also found that adding all interventions together had the strongest effect indicating that a combination of strategies might have the best result for increasing sustainable behaviour. Overall, this selection of intervention studies shows that combining psychological and structural measures can be successful, but more research is needed to fully understand which elements are key, for how long effects last and for whom interventions work.

4.4 Clean-Up Initiatives that Involve Citizens and Other Stakeholders

There are many different clean-up initiatives around the world, which involve citizens as well as other specialist groups such as school groups, scuba divers and fishers. As well as having an immediate effect on the environment (removing litter from the environment), they in themselves can be seen as an intervention to encourage greater behaviour change. Two examples include the 'Fishing For Litter' scheme and beach cleans. The Fishing For Litter scheme in Europe involves commercial fishers and asks them to retain any litter found in their everyday catch and bring to port to dispose of. It is argued that focusing more on intrinsic motivation (via raising awareness, promoting a positive attitude towards the issue, and emphasising the acceptance of the scheme within the community) rather than focusing on extrinsic motivation (i.e. paying the fishers) has been effective in recruiting and retaining UK fishers [35]. An evaluation of this scheme in the UK found a potential spill over effect: fishers participating in this scheme also reported adjusting their waste disposal practices at home [35].

Another example is citizen science clean-ups, where volunteers both remove and record items of waste (e.g. [31]). These activities have numerous benefits, from improving the cleanliness of the immediate environment directly to contributing to scientific data that aids our understanding of the composition, distribution and sources of aquatic waste [65]. There are also benefits for the volunteers such as finding the activity enjoyable and rewarding and raising awareness further as well as encouraging other plastic-related behaviours (e.g. declining single-use items, recycling, encouraging others to participate [66]). Thus, working with other disciplines, environmental psychologists can investigate what the co-benefits of these inclusive clean-up initiatives are and how to maximise those [67]. However, it also needs to be stated that we cannot solely rely on clean-ups to resolve the plastic pollution problem; we need a more integrated systemic approach that addresses the sources and pathways much earlier.

4.5 When Is an Intervention a Behaviour Change Intervention?

Above we have focused on the role of behaviour and behaviour change interventions, specifically those that have been evaluated in some way (e.g. [47, 54]). We have selected interventions that deliberately target behaviours, many building on specific theories of behaviour change that provide a structured conceptual framework. But indeed, a wide range of actions may change behaviour either in a desired direction or in the opposite direction. We have not reviewed educational programmes in detail that tend to focus on raising awareness and education (as implied in the name). Education and public outreach campaigns are often crucial in preparing or accompanying policy change and are powerful tools in their own right. For example, Lawson et al. [68] tested the effects of a climate change education programme in schools and found that the intervention increased climate change concern in both the school children and their parents. Fathers were influenced most strongly, and daughters exerted the strongest influence. This is a great example of an educational intervention that was tested rigorously using an experimental design that demonstrated positive effects not only on the children themselves but also via social transmission on their parents. We need more studies such as this one to investigate the effects of environmental information and education programmes for plastic pollution. This could also be extended to the various engagement programmes that involve arts and creative approaches, which are popular in the plastic pollution field. Such studies should include measures of behaviour too. We must not assume that these programmes always work in the intended way but ask for more evidence that will help develop better programmes and avoid unintended consequences. Even highly funded rigorous behaviour change programmes focusing on health do not necessarily find the desired effects (e.g. [69]), so establishing better evidence surrounding interventions is a key task.

We have focused on mechanisms of change so far, because sustained change is the most challenging and elusive achievement, with considerable research gaps especially at larger scales. We have argued that risk perception and concern are one predictor of change and that media reporting affects risk perceptions in the population (see also Fig. 1). So in the next part of this chapter, we briefly review insights on media reporting and risk perception that are relevant to plastic pollution.

5 Media Reporting, Concern and Risk Perception

Increased reporting of harm to wildlife has been documented in scientific articles and in the wider media. Coverage of plastic pollution is growing even for specific issues that have only emerged very recently. For example, media coverage of microplastics has increased from near zero to over a thousand items per month just between January 2017 and October 2018 [6]. This follows a dramatic increase in scientific

publications on microplastics between 2011 and 2018 (in general and in relation to food for human consumption in particular [6]). Large quantities of plastic lost into the environment mean that aesthetic and wildlife impacts are now widely visible and frequently reported in the media, and this is associated with a high level of public awareness and demand for action [6]. Over the last few years, high problem awareness has been observed (e.g. [70]), as well as a consensus between different groups in society. Together these form a momentum for change not previously seen for other environmental challenges, as evidenced by increased action. For example, participant numbers in beach cleans in the UK have doubled [6].

What specific plastic risks are people concerned about, and how does plastic concern compare with other environmental issues? In line with the focus in scientific and media reports on wildlife impacts, Hartley and colleagues found that Europeans were highly concerned about litter impacts on marine environments but less concerned about human health impacts and economic impacts such as tourism and shipping ([36], data collected in 2015). Commercial fishers, as a highly affected stakeholder group, also reported high levels of concern about plastic pollution [35]. Overall, pollution has been consistently named as top concern in perception research focusing on marine and coastal environments over the last 15 years [71–73], although social data on other aquatic systems is lacking. More recent research by Dilkes-Hoffman et al. [70] showed that the three environmental threats rated as most serious were plastic and waste related, with number one being 'plastic in the ocean', whereas air pollution, water shortages and climate change were rated as relatively less serious (although still serious in absolute terms). In addition to these quantitative findings, qualitative studies have used open questions to explore people's perceptions and have found low awareness of microplastic presence, for example, in personal care products [30]. Awareness mostly seemed to revolve around macroplastic pollution; however, some groups appear to be more knowledgeable than others, with people using the water for leisure activities showing awareness about various aspects of plastic pollution [33].

Recently, there has been increased coverage of potential human health effects related to plastic pollution and exposure from everyday plastics (see also section on challenges below). Specifically, exposure to microplastics (e.g. via food and drink) and potential toxicological effects of plastic additives seem to capture attention. However, perception data on this is not yet available. For example, the most recent Eurobarometer, using data from December 2019, tells us that 88% of people across the EU are worried about the environmental impact of microplastics, but no parallel question was asked regarding worry about the human health impact [74]. However, as early as 2016, German citizens reported feeling contaminated by microplastics in food (BMUP/UBA, 2016, reported in [6]). Within the European SOPHIE project (Seas and Oceans for Public Health in Europe, https://sophie2020.eu), a large-scale European social survey asked specifically about the perceived risks of different marine threats for human health and wellbeing. Davison et al. [75] report that plastic is of the highest concern here, above other threats.

On the whole, there is now undoubtedly high concern about plastic pollution in general; compared to other major environmental challenges, there appears to be no

denial of the problem of plastic pollution, and the public demands action across society. Having said this, some aspects of plastic pollution are more widely understood (wildlife impacts), while others are emerging (potential human health impacts). This wide acknowledgement of the problem puts plastic pollution into an exceptional role that is different from the societal response we have seen to other environmental threats. For example, for climate change, there is considerable denial at least partly fuelled by lobbying groups and huge polarisation along political lines [76].

What factors underlie concern? Hartley et al. [36] showed that psychological factors such as values and social norms were associated with marine litter concern (around 80% of which are plastic). Altruistic-biospheric values, in other words attributing great importance to the natural world and to the wellbeing of other people, were positively associated with concern, but there was no relationship between egoistic values (indicating a focus on oneself) and concern. Experiencing direct evidence of the problem, measured by the frequency of noticing litter, was also associated positively with concern. The only sociodemographic variable that had a similar size association in this study was education level, with more educated respondents reporting more concern.

6 Risk Perception and Communication: Broader Principles

Slovic [77] observed: 'Danger is real, but risk is socially constructed'. Socio-environmental risks are typically high in complexity and uncertainty; they comprise risks for and from the environment and they are due to the aggregated behaviour of many individuals. In this section we briefly review some more generic principles of risk perception and communication that matter in the context of plastic pollution.

One characteristic of environmental risks that inhibits concern and behaviour change is psychological distance across three dimensions [78]. First, environmental impacts can be temporally distant in terms of consequences of our actions today happening in the far future. Second, impacts can be geographically distant, leading to the impression of the local area being relatively unaffected (e.g. higher rates of plastic use and pollution in the USA than in Europe). Third, impacts can be socially distant: seemingly happening to others different in culture and context (e.g. the message that the most polluted rivers are located in South East Asia, from a European perspective).

Lack of visibility, particularly for very small plastic particles, could be an important feature of plastic pollution that may be linked to a feeling of distance and inaction. If an issue cannot be directly observed and assessed, public risk perception must rely on other sources, e.g. trust in experts [79], and behavioural feedback as a mechanism of change is difficult to enable [80]. More research is needed to explore this hypothesis for plastic pollution. Relatedly, the heuristics and biases literature describes the formation of risk judgements [81]. Heuristics and biases are mental shortcuts that people use to make sense of information such as the

availability heuristic (what's easy to imagine is perceived as high risk), anchoring-and-adjustment (an initial value will influence the final judgement even if irrelevant to the issue) and the affect heuristic (affective and emotional states influence judgement; see Böhm and Tanner [82], for overview).

In addition to these more cognitive processes, ethical and fairness considerations play a key role in people's risk perception: do the risks arise to the same people or groups that cause them, or is the burden unfairly distributed [82]? While there is good evidence for the principles described so far for human decision-making in general, there are also differences between individuals. People differ in what they use as the basis for their risk judgements, with some people relying on cost-benefit trade-offs more and others relying on moralistic considerations more, such as the inherent rightness or wrongness of an issue [6]. Additional influences on risk perception are values. People with higher altruistic and biospheric values (relatively to egoistic and hedonic values) have higher environmental risk perception (see [36, 53]).

Why is there sometimes conflict between expert and non-expert views? Research has found differences between experts' and non-experts' risk perceptions (see [82]). Experts apply scientific methods of risk assessment that focus on specific thresholds or outcomes such as fatalities or concentrations, whereas non-experts' judgements are determined by a wide range of factors, some of which are noted above (moral evaluation of the issue, perceived fairness, perceived control, positive and negative emotions such as dread and pride, etc.). These discrepancies can contribute to conflict between different stakeholders. Moreover, sometimes the public is more worried about a risk than experts are (social amplification), and sometimes the public is less worried than experts are (social attenuation [83]). Exploratory data reported in a GESAMP [8] report showed that experts rated the risks of microplastics higher than did a small convenience sample of UK adults. While scientists may be tempted to claim that expert assessments are the rational ones and non-experts are simply irrational, this definition of rationality appears simplistic and could be problematic when attempting to manage risks. Capturing these perceptions more systematically through social science methods is important and provides a different kind of evidence base that helps manage the system, especially for emerging risks that are covered widely by the media.

Mental models approaches [84] capture and analyse people's understanding of pathways and processes related to specific risks, often in order to compare expert and non-expert views. Mental models can visualise and compare different expectations about the sources and impact of hazards, which can then be used to tailor risk communications and resolve conflict. As a recent example of a mental model approach combined with digital technology, the MECCA project (https://mecca.sites.uu.nl/) captures mental models created by stakeholders from East and West Africa via a portable tool, to understand people's perception of climate change and risk but also to develop targeted communication strategies for mitigation. This approach allows the integration of community perspectives into decision-making processes responding to environmental risks. The H2020 LimnoPlast project will apply a mental models approach to microplastics in freshwater for the first time (https://www.limnoplast-itn.eu/).

7 International Dimension

In social and environmental psychology, samples from Western, educated, industrialised, rich and democratic (WEIRD) societies are overrepresented, and we have a lot to learn from other disciplines such as anthropology and sustainable development studies. These WEIRD samples mostly appear to reflect the country of residence of the authors, even if they only represent about 12% of the world's population [85, 86]. WEIRD samples differ from other samples in characteristics such as risk perception, economic decision-making, concepts of cooperation, self-concept and moral reasoning [87]. On the other hand, humans across the world also have many characteristics in common, such as emotional expression, patterns of specific social relationships to name just a few [87]. The gap between Western and non-Western samples needs to be acknowledged also when it comes to addressing plastic pollution.

Simmons and Fielding [88] recently investigated predictors of waste management and fishing behaviours in coastal communities in Indonesia. Despite many similarities to findings from Western samples, some relevant differences were identified. In their study, positive attitudes towards waste disposal as well as perceived behavioural control emerged as the most powerful predictors of sustainable waste management practices, which is in line with previous studies [51]. Despite social norms emerging as one of the most powerful predictor in many other studies measuring predictors of environmental behaviour [47, 89, 90], this variable did not emerge as a significant predictor of sustainable waste management of fishing in the coastal communities of Indonesia. Instead, the perception of positive change and contextual factors was found to precede sustainable waste management practices. In line with the finding by Simmons and Fielding [88] that contextual factors seem to be crucial for people to engage in sustainable handling of plastic, Singhirunnusorn et al. [91] also found that, despite awareness and attitudes contributing to people participating in community based sustainability projects, it was the context that brought the biggest measurable effects. In Iran, sustainable handling of household waste was found to be predicted by an extended form of the Theory of Planned Behaviour [92], in which the added variable 'moral obligation' played the most important role across three studies [93]. In Thailand, social norms were not found to be a significant predictor of purchasing sustainable fashion made from recycled plastic; instead it was environmental concern that explained the largest amount of variance [94, 95].

An interesting global communality is that when it comes to recycling in particular, it seems that across samples in India [94, 95], South Africa [96] and the Global North [22, 97, 98], social norms seem to be the strongest psychological predictor. Differences can be found in demographic factors, as, for example, relatively young people between 25 and 35 were the group reported to recycle the most in Bangladesh [99], whereas in Malaysia this was the oldest age group above 65 [100], and a meta-analysis across 63 studies showed that in (mostly) Western countries it was adults between 36 and 65 who seem to be most willing to recycle [101].

In sum, environmental psychology is increasingly focusing on understanding sustainable behaviour change beyond Western societies, but there are still many gaps to fill. Programmes such as the Global Challenges Research Fund in the UK (https://www.ukri.org/research/global-challenges-research-fund/) help this effort and aim to empower researchers by placing particular emphasis on mutual capacity building, interdisciplinary and international cooperation to strengthen research activities in developing countries related to the Sustainable Development Goals.

8 Challenges

While great progress has been made in our knowledge about plastic pollution, some challenges remain. The potential risks to human health are one such challenge. While media and NGO campaigns have discussed potential human health impacts, particularly of microplastics, there is currently not enough scientific evidence to establish risks conclusively, whether it is via ingestion or inhalation [6], and it has been questioned whether human health risks of plastics, especially microplastics from food and beverages, have been overestimated compared to other human health risks and pathways [102]. It seems that in public discourse, the *presence of microplastics* in the environment (which has been established conclusively) is sometimes conflated with the *presence of risk* and *harm* (for which assessment is incomplete). We do not currently know if microplastic particles taken up with food are simply passing through organisms (including humans) or if they are having adverse impacts. This absence of evidence does not indicate an absence of risk, nor does it indicate absence of *risk perception*. With such a fast-moving topic, policy makers may see public demand for action before the scientific evidence is robust, and that puts them in a difficult position when pursuing evidence-based policy [103]. While there is little research specifically on the uptake of these messages in the public and on motivations by the communicator, it can also be observed that these existing messages are at the more extreme, negative end of the spectrum. Psychological research has shown that 'bad is stronger than good', meaning that negative content leaves stronger memory traces and is harder to 'undo' [104]. So even if some of the human health claims might never be supported by conclusive evidence, they may remain in the public understanding for some time.

It has also been questioned if plastic is receiving 'too much' attention in comparison with other environmental hazards such as chemical pollution or climate change [6]. We can only speculate why this might be the case; it could be because plastic is an everyday material that is visible and familiar in most of its manifestations, as opposed to, say, carbon dioxide. Nevertheless, people might not connect their everyday decisions to the impact of plastic waste. When they do their shopping in the supermarket, it is likely that product appearance, price, taste and convenience matter more to most people [105], apart from those very high in awareness and engaged in conservation. The challenge here is to connect consumer decisions to those impacts and motivate better consumer practices as well as motivate pressure on

industry to reduce single-use plastic and offer more sustainable options. As indicated above, harnessing ocean connectedness and more general nature connectedness might be one possibility for connecting the dots [1, 48].

Another disconnect has been described by Newman et al. [106] relating to the economic system. They observed that the price of plastic does not include the cost of recycling and disposal, which are currently shouldered by society. This maintains a system of production and consumption of plastic at low prices, posing another disconnect between the experienced benefits of the material and the end-of-pipe costs and impacts. Both the economic drivers and behavioural processes ought to be considered alongside the natural science perspectives [6].

A final challenge relates to the 'unknowns'. Before 2020, discussion on plastic pollution centred around the plastic system as illustrated in Fig. 1, and researchers were working on a defined set of drivers. Then a new health pandemic hit: COVID-19. In the wake of COVID-19, concern about plastic pollution and plastic-reduction behaviour seem to have decreased, probably because of both changed priorities (staying safe and healthy being of higher concern) and changed systems (e.g. the hospitality sector in many countries only being allowed to serve take-away at the time of writing this chapter). Plastic is used in the form of single-use protective gear and packaging for hygiene and protection from the virus, again showing its usefulness and versatility [107]. On the other hand, this increased use is likely to have direct effects in terms of increased plastic pollution of these items and may even pose additional contagion risks [108].

9 Research Gaps

Plastic pollution is an established research field, yet new challenges are continuously emerging, and many research questions remain unanswered. Research has primarily been undertaken in different scientific disciplines working separately, but plastic pollution is a problem that requires holistic and systems-based analysis. There are some encouraging signs that this is changing, with recent funding programmes on plastic requiring interdisciplinary approaches (e.g. the European Commission's H2020 and Horizon Europe programmes) and supporting international exchange and capacity building (e.g. the Association of Commonwealth Universities' Blue Charter Fellowships).

In 2018, we had the opportunity to ask a group of UK industry experts what they thought the state of the evidence was regarding plastic pollution and interventions [109]. This was at an event bringing together plastic producers, recyclers, retailers, etc. Figure 2 shows that industry experts felt there were still considerable gaps in the evidence. From left to right in Fig. 2, they reported the highest amount of evidence we have was for harm to marine environments and wildlife (but this was only a 'fair' amount of evidence rather than 'good' or 'very good'), with less evidence available for terrestrial environments and human health. Industry experts also thought that the evidence for the effectiveness of new technical approaches and materials and for potential policy interventions was only between *poor* and *fair*, and evidence for

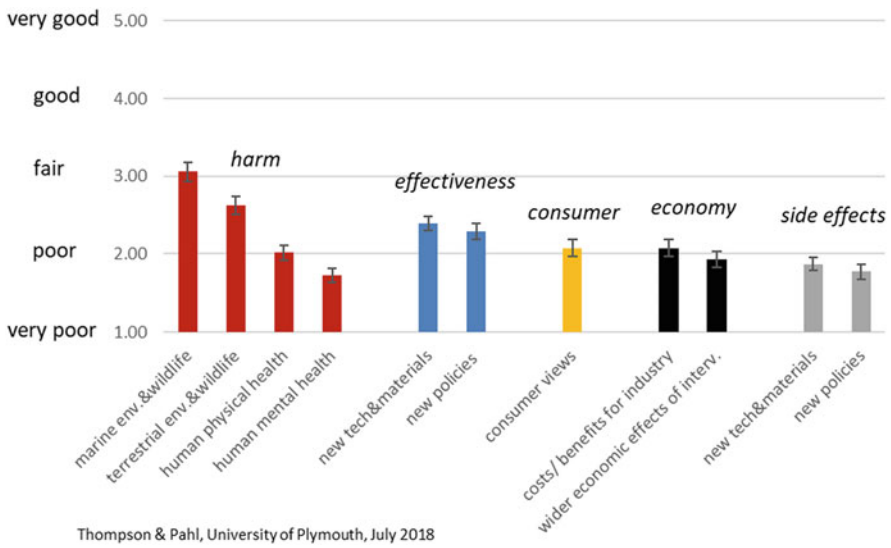

Fig. 2 Expert views ($N = 71$) on current state of the evidence regarding plastic pollution and interventions (entire response scale shown, from very poor to very good)

consumer responses to potential interventions was *poor*. Ratings relating to evidence for economic effects of interventions and potential side effects were also very low. These data clearly show that industry representatives see data gaps, and hopefully the results also show a desire to develop solutions that are evidence-based.

As previewed by the earlier discussion, we also need more robust data on perceptions and concerns related to plastic pollution, especially in the context of freshwater and other pathways, because marine contexts have seen a comparatively higher research focus. We need more social data on the emerging risks of plastics such as micro- (and the emerging issue of nano-) plastics and on human health risks, and we need to set these perceptions in the context of other concerns. Another key question is what people think about different solutions, what they are prepared to change in their own lives and what types of policies and system changes they are prepared to support.

In tandem with additional perceptions research, we urgently need research on interventions not only to understand and quantify what these can achieve in target outcomes (plastic pollution) but also to understand potential co-benefits and side effects (e.g. carbon footprint, food waste, etc., https://www.wrap.org.uk/blog/2018/04/unintended-consequences-war-plastic). This requires interdisciplinary research to pinpoint the human response and identify facilitators and barriers to successful change and resilience of suggested solutions (as some things are quite unpredictable, such as global pandemics). It is crucial to understand behavioural responses to technical and systems change, to counteract adaptations that result in additional problems and to understand where a single prominent action might overshadow the need for much bigger change and where industry and other actors may engage in

'greenwashing' (giving misleading information or over exaggerating actions to appear more pro-environmental than they actually are).

A particular gap appears to be around quantifying the behavioural dimension, so that this can be integrated in analyses of plastic flows. Dietz et al. [110] analysed the role of behavioural intervention for energy consumption and highlighted two key factors: the 'plasticity' or potential of change in that behaviour and the effectiveness of the change in addressing the problem in terms of emission reduction. In other words, how feasible would it be to change that behaviour, and how impactful would this change be? This type of analysis would be extremely useful in the plastic pollution context.

In addition to understanding the role of behaviour per se, more comprehensive evaluation of interventions needs to take place, whether they are educational or information-based, designed as behaviour change programmes in the community, or triggered by technological or systems change. These insights will allow us to design better interventions that integrate more smoothly.

10 Summary and Conclusions

Plastic pollution is a topic that many different groups in society feel strongly about. We have not seen evidence for plastic pollution denial comparable to climate change denial, which is a great starting point for change. However, we need to understand better how social perceptions and interactions are shaped in the context of news stories and NGO campaigns that are sometimes out of step with scientific evidence. We need to work with society and build robust evidence for establishing better production, usage and disposal systems, and we need to make sure this evidence is accessible and used.

Programmes of change should build on behavioural science insights, for example, from social and environmental psychology and integrate key elements that have been shown to work, e.g. empowerment, specific suggestions for behavioural solutions that are effective, feasible and acceptable. We need to investigate societal change processes from individual behaviour to communities and bigger groups, while approaches need to encompass social identities, social norms and other predictors of behaviour change, going beyond an information/education focus. It is advisable not to crowd out intrinsic motivation but rather build on personal and social norms and values, as this could lead to spillover into other pro-environmental domains and behaviours and motivate support for new policies and other top-down interventions. Effective interventions link to the target group's understanding of the issue, to their motivations and concerns, and they build on existing social networks and channels. If there is initial reluctance to change (such as we have seen around introduction of seat belts or smoking bans in the past), early adopters can make a difference [111]. Trusted members of a community can trigger wider change and could be empowered as change agents [56]. Change can happen top-down and bottom-up, including individual change and community action, but

also through voluntary industry initiatives and new regulation. When these processes join together, we can achieve a real reduction of plastic pollution in our aquatic environments.

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Society Role in the Reduction of Plastic Pollution

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Abstract Globally, plastic pollution generates a dramatic environmental impact, posing an increasing hazard to wildlife and human health. Complex measures are needed at the societal level to curb this pollution trend: from changing consumer behavior, enhanced research for innovative solutions to reduce plastic production and increase plastic recycling ratio, to the usage of environmentally friendlier alternatives, improved awareness raising, and information dissemination at wider scales. There are multiple possibilities for public and stakeholders to break the plastic pollution chain: education, research, environmental NGOs, plastic industry, local authorities, policy makers, and citizens – all can play an active role in the battle against pollution. This chapter presents the ways to induce an attitude shift at the societal level toward reduction of plastic pollution, by emphasizing the risks of plastic pollution, possibilities to change consumer behavior, examples of best practices to reduce pollution and improve plastic waste management, highlighting how education and science can improve our daily decisions toward green solutions, how social media can support with dedicated applications and awareness-raising campaigns, and how each stakeholder can contribute to tackle this global challenge.

Keywords Awareness raising, Consumer behavior, Plastic recycling, Plastic waste management

1 The Global Dimension of Plastic Pollution

Plastic pollution generates an increasing concern at the global scale. While plastic products can improve the quality of human life, nearly half of the plastic production worldwide generates a substantial amount of waste, causing negative environmental impacts in case of inappropriate disposal. Following the increasing demographic trends and technical developments, plastic production has increased dramatically over the past decades, from a production of 1.7 million tons worldwide in 1950 to nearly 360 million tons in 2018 [1]. At the present rate, this value is estimated to double within the next 20 years, accounting for 20% of the global oil consumption and 15% of the annual carbon emissions by 2050 [2]. In a business-as-usual scenario, this projected increase in plastic production will most likely result in a concomitant increase in the accumulation of mismanaged plastic waste in the environment, which is projected to triple to 155–265 million ton $year^{-1}$ by the year 2060 [3].

Most plastic litter enters the environment through inappropriate disposal and/or management of plastic products. It is considered that about 80% of plastic pollution in the marine environment originates from land-based sources [4]: only in 2010, between 4.8 and 12.7 million metric tons of mismanaged plastic waste entered the oceans globally [5], either through direct input into the sea or via rivers, activities on the shoreline, shipping, and fisheries.

At the global level, the Asian continent contributes in the highest extent to plastic waste generation and pollution. For example, in 2015 the top five regions generating plastic waste were Asia (82 million ton), followed by Europe (31 million ton), Northern America (29 million ton), Latin America (19 million ton), and Africa (19 million ton); however, the proportion of inappropriate plastic waste disposal, responsible for plastic pollution, showed a different ranking: Asia released an average of 52 million ton of plastic waste into the environment, followed by Africa (17 million ton), Latin America (7.9 million ton), Europe (3.3 million ton), and North America (0.3 million ton) [3]. The authors conclude that the unfair practice of importing waste, especially e-waste, from developed nations, is to a large part responsible for this problem, e.g., in Africa ([6], cited in [3]). These data show that the plastic pollution problem is more acute in developing countries; moreover, moving plastic waste from developed countries to developing areas only increases the problem, without offering real solutions to reducing plastic pollution. Hence, additional efforts to improve plastic management should be made by all countries, especially by those producing high amounts of plastic.

Once entered in seas and oceans, floating plastics are driven by currents, accumulating in large patches and gyres, the largest one being the Great Pacific Garbage Patch, located in the North Central Pacific Ocean, between Hawaii and California. The aerial estimates of this area covered by plastic waste trapped by winds and currents indicated in 2018 a surface of over three times the size of continental France rapidly growing due to increasing amounts of plastic waste brought in the area [7]. However, this is only the tip of the iceberg, with floating plastic debris representing only 5% of the total, while the rest of 95% are submerged [8], making it impossible to clean all plastic waste from the marine environment.

While most plastic debris are generated by an inappropriate collection/recycling of plastic products, microplastics originate either from the fragmentation of macroplastic products, like packaging, textiles, dyes, car tires, etc. (secondary microplastics), from industrial products containing added microplastic particles such as cosmetics and healthcare products (cleansers, exfoliators, toothpastes, sunscreen creams), or from synthetic fiber clothes [9]. These so-called primary microplastics also include, e.g., industrial raw pellets, ion exchange resins, sand blasting media, etc. Microplastics can be transported by wind, washed into aquatic environments by runoff, or released from wastewater treatment plants, where they are incompletely retained during purification processes and then discharged into rivers and waterways [10].

2 Why Do We Need to Reduce Plastic Pollution?

Besides the aesthetically detrimental aspects generated by the ubiquitous presence of the plastic debris in the environment, even on remote beaches (Fig. 1), it is becoming increasingly clear that plastic pollution can have negative impacts on the aquatic environment, with one of the most obvious effects being the increased incidence of ingestion and entanglement of marine birds, amphibians, and mammals due to plastic litter [11, 12].

There are still significant knowledge gaps regarding plastic presence and impact in freshwater bodies, especially in rivers that act as transport vectors (Fig. 2), connecting the land-based pollution sources to the seas/oceans [13]. Preliminary investigations of several European rivers (Rhine, Main, Danube) have emphasized the presence of plastic pollutants [14], but the extent of this contamination and its impact on water quality and aquatic biota, including on game and fish used for human consumption, are unknown. An alarm signal was already raised by researchers, as synthetic polymers such as polyethylene, polypropylene, and polystyrene are frequently found in rivers [15], while the contribution of other compounds still needs to be assessed. It has been shown, however, that a variety of different polymers is introduced into aquatic environments by wastewater treatment plant effluents [16]. Considering that river water has multiple uses for human society (drinking water, water for irrigation and livestock, fishery and aquaculture, food industry, etc.), the likelihood for the ingestion and transfer of the plastic present in the rivers into the food chain increases with the pollution.

Fig. 1 Plastic waste along remote beaches (Marinella di Sarzana, Italy). Photo credit: Franco Borgogno

Fig. 2 Plastic waste accumulation along inland rivers (Po River, Italy). Photo credit: Franco Borgogno, LIFE VISPO project

Regardless of their entry source, once arrived in the aquatic environment, plastic particles can impact not only large vertebrates but also other living organisms, posing possible hazard also on human health [17, 18].

The risks to wildlife generally fall into three main categories:

(a) Physical harm (e.g., entanglement, irritation/blockage/perforation of the digestive system, false satiety, suffocation/damage to benthic systems)
(b) Chemical harm (from toxic chemicals associated with plastic such as additives, persistent organic pollutants, heavy metals, etc.)
(c) Biological harm (e.g., from microorganisms that adhere to plastics)

Entanglement and ingestion of macrodebris by large vertebrates is undoubtedly a significant issue (Figs. 3 and 4); however, microplastics can also be ingested by aquatic organisms and transferred along the food webs [19].

Moreover, unaware of the danger, birds use plastic debris to build up their nests [20], exposing their offsprings to possible accidents in early life stages (entanglement, ingestion of plastic particles with the food) (Fig. 5).

In general, negative consequences of plastic on aquatic fauna include loss of nutritional value of diet, false satiety, impaired reproduction, physical damages, exposure to pathogens, and transport of alien species [21, 22]. In addition, plastics contain chemical additives able to leach into the environment and the food and

Fig. 3 Two male specimens of common eider (*Somateria mollissima*) entangled in an abandoned fishing net while diving to hunt small fish in the Gulf of La Spezia, Italy (Photo credit: Davide Lopresti)

Fig. 4 Young subantarctic fur seal (*Arctocephalus tropicalis*) entangled in plastic strings and ropes (Photo credit: Peter G. Ryan)

drinks we consume and efficiently adsorb other toxic environmental contaminants (e.g., endocrine disruptors), thus constituting a potential source of exposure to such compounds after ingestion [22]. The capacity of plastic particles to act as transport

Fig. 5 The Northern Gannets nest of Portovenere (Italy), built over the deck of a boat using large amounts of plastic materials. Reproduced from [20] with permission of the authors

vectors for other toxic pollutants, as well as their bioavailability through the trophic networks, increases the risks for wildlife and human health, but the ecological significance of this issue is still under discussion among scientists [23].

The ingestion of microplastic particles has been demonstrated in a wide range of marine organisms consumed as food by humans, such as molluscs [24, 25], crustaceans [26], and several fish species of commercial interest [27–33]. In addition to wild organisms, also those from aquaculture have been observed to ingest microplastics [34–36]. The presence of microplastics has also been detected in seafood sold for human consumption purchased from markets around the world [37–39]. It should be noted, however, that human ingestion of large microplastics via seafood is probably more common for shellfish and small fish which are eaten entirely including the gastrointestinal tract and probably less frequent for large fish which are generally eviscerated before consumption, thus minimizing direct exposure to microplastics.

All this evidence raises concerns regarding the consumption of microplastics by humans, though, at the current levels of contamination, the hazard on human health needs further evaluation. More recently, the potential risk of nanoplastics (<1 μm in one dimension) in seafood is being recognized [40], even though research is still in its infancy. Compared to microplastics, nanoplastics have an increased mobility in the tissues of living organisms [41], and their larger surface to volume ratio increases their potential to adsorb and concentrate toxic chemicals and heavy metals [42]. Translocation of plastic particles across the gastrointestinal tract has been demonstrated in the laboratory for crabs [43] and mussels [44] and in the liver of fish fed with plastic particles [45]. Within this context, being more prone to translocation across biological tissues, nanoplastics would pose a greater potential

risk to human health [46]. However, impacts and environmental concentrations of nanoplastics are still largely understudied, and the risk posed to marine organisms as well as to humans who consume seafood requires further detailed research.

Plastic also has a significant contribution to climate change impacts. Plastic manufacturing is estimated to use 4–8% of yearly global oil production, and it was estimated that around 5 ounces of carbon dioxide are emitted for each ounce of PET produced [47]. Processing plastic resins and global transportation also have a carbon footprint, with estimates showing that one 0.5 l PET bottle has a total carbon footprint equal to 82.8 g of CO_2 [48]. In addition, also the accumulation of plastic litter in the environment is raising concern for potentially contributing to carbon emissions, with recent research showing that polyethylene and other commonly used polymers can release substantial amounts of dissolved organic carbon into the ambient seawater [49] and greenhouse gases (methane and ethylene) into the atmosphere, when exposed to solar radiation [50].

As the plastic pollution was generated by human society and now turns back like a boomerang, affecting environment and human health, it is our responsibility to take action and reverse the current pollution trends. Science, education, stakeholders involved in the plastic cycle, NGOs and the general public all have a major role to play in the next years, each one contributing with essential pieces to solve the complex puzzle of plastic pollution.

3 Role of Research and Education

In the last decade, the focus on emerging water contaminants was mostly placed on pharmaceuticals, persistent organic pollutants, and nanomaterials. In recent years, however, a new suite of contaminants, predominantly microplastics, received increasing attention after being frequently detected in marine, and more recently in continental waters and sediments, and after the alarm signals pulled by scientists regarding the potential risks they pose to biota. In this context, macroplastic contamination is also of very high concern.

3.1 Research

Although research concerning the impact of plastic on the aquatic biota is in its early beginning, the studies performed so far already emphasize that plastic particles can negatively impact aquatic wildlife and human health [51].

Preliminary investigations have indicated the capacity of microplastics, and the pollutants associated with their presence, to bypass wastewater treatment plants and enter the trophic food chains at low trophic levels, from where, through bioaccumulation and biomagnification, they can also reach end consumers [52].

Considering the widespread use of freshwater for drinking or agriculture and the fact that many aquatic species are used as food source (fish, crayfish, mussels, etc.), it is easy to understand that contaminated drinks and food also reach humans.

Research was paramount to reveal the contamination levels of microplastics and microfibers in many food and drink products intended for human consumption such as honey [53], salt [54], beer [55], and drinking and tap water (see [56] for a review), triggering in this way surprising reactions from the public opinion and the decision-makers as well.

However, there are still many challenges ahead, such as highlighting the level of plastic contamination in general, emphasizing polymers occurring with higher frequency and higher concentrations in the natural environment [57], assessing plastic uptake, accumulation, and transfer rates to different aquatic organisms and human bodies, and evaluating their ecotoxicological impact [18, 58] and effects on health (life cycle parameters, metabolism, stress) – in conclusion, enabling a reliable risk assessment, tracking the pollution sources, and recommending ways to phase them out. Interdisciplinary studies combining chemistry, biology, toxicology, ecotoxicology, and health sciences should be directed toward the identification of high-risk plastic substances and for substituting their use with environmentally friendlier products (paper, wood, bioplastics, etc.).

Research should also be directed on studying the plastic impact on aquatic habitats and innovative ways to restore polluted sites. Collecting plastic from aquatic habitats is a big challenge especially in dynamic rivers, which are constantly changing their characteristics. While for macroplastic the collection is easier (floating in pools near the river banks, in the vicinity of obstacles such as trees or dams, or from the river banks and adjacent floodplains) and plastic items can be recycled, microplastic particles already released into the environment are too small to be eliminated without affecting habitats and biota. Creating buffer strips along the rivers (wetlands, floodplain forest) to retain plastic products and facilitate their collection, improving the efficiency of microplastic retention in wastewater treatment facilities by including additional filtration steps, designing innovative solutions to prevent plastic to reach the rivers should be explored as possible solutions to reduce the plastic input into the aquatic environment.

Replacing the most common single-use synthetic polymers, for instance, with biodegradable polymers, is often considered as one of the most effective solutions to solve the plastic pollution crisis [59]. Research into the degradation times and environmental effects of these new polymers, however, is still in its infancy – especially in the marine environment where many biodegradable and oxo-degradable materials showed much lower degradation rates than in laboratory conditions [60] – and instruments such as the Life Cycle Assessment (LCA) should be always used to clearly point out the benefits or the disadvantages of using these new polymers before adopting binding legislative decisions (e.g., [61, 62]).

3.2 Education

Education has a key role in shaping a responsible behavior of the future adults. Considering that reducing plastic pollution is a long-term endeavor, it is essential that children and young people receive sound knowledge concerning the effects of plastic pollution and ways to reduce its impact by our daily behavior, as they represent the future generations.

Educational programs prepared for pupils may include classrooms and outdoors experiences to learn about how much plastic they daily use, plastic impact on the environment, particularly on rivers and seas, how human life is connected to the freshwater ecosystems, how aquatic pollution may affect them, the importance of reducing the use of plastic, reusing it, and recycling it, and, finally, how important it is to avoid littering in general. Beyond the environmental problem of plastic waste and with respect to limited fossil resources, such programs should also distribute the knowledge that plastic waste has a high energetic value and can be used for energy recovery – thus plastic littering is not only of environmental concern but also represents a waste of energy.

The involvement of pupils in such activities can be further pursued by field trainings to observe plastic pollution and communicate their results, school contests and participation in river, lake, and beach cleaning actions (Figs. 6 and 7), and

Fig. 6 Children cleaning up the bank of the Meuse River, Netherlands. Photo credit: Gijsbert Tweehuysen

Fig. 7 Teenagers collecting plastic waste (Po River, Italy). Photo credit: Franco Borgogno, LIFE VISPO project

activities that are meant to stimulate their willingness to act as volunteers, advocating and disseminating within their families and groups the information acquired about the need to reduce plastic pollution.

One of the education programs in Italy and Hungary promoted by the European Research Institute (ERI) based on the UNESCO guidelines [63] and toolkit [64] is about Ocean Literacy. The program takes into account the fact that most people are unaware of the impact of their daily actions on the health and sustainability of the oceans and the resources they provide. This program strengthens the understanding of the importance of ocean health for human lives at the social, economic, and political level since early ages. Special focus is placed on students, where using short presentations and combining education with cleaning plastic waste activities target an attitude change by cognitive, socio-emotional, and behavioral learning. A successful cooperation was also established with schools, targeting the organization of joint education events such as collection of plastic waste along the river shores and sea.

The education ideas formulated by ERI are based on the so-called de-linearizing learning approach [65], supporting people to overcome challenges and identifying four important roles in learning: student, teacher, researcher, and practitioner, all of which should be used by each individual in the education process. The education process follows a three steps sequence:

- *The process of acquiring, making accessible, and where necessary, developing new knowledge and skills*, where finding appropriate knowledge is essential to define the requirements for a collaboration system facilitating the learning process.
- *Assessment and quality assurance*: Given the fact that every person involved in the learning process can play the role of a supplier of knowledge (teacher or researcher role), the quality of the information itself should be assessed.
- *Integrating into the worldview* – the actual teaching process, where a growing number of specialists will be involved in the teaching process, resulting in the challenge of integrating the insights of the specialist into the existing world-views and/or systems of values and norms. Thinking concerning the roles an individual play makes it possible to introduce different levels of involvement at the individual, organizational, or societal level.

This type of education has an important role in the innovation capacity of people and offers practical experiences, thus being a very useful and successful methodology.

To ensure that the latest research findings on the issue of microplastics in marine ecosystems are directly incorporated into school lessons, marine researchers and museum educators have jointly developed teaching materials for four school levels as part of the PlasticSchool project in Germany, which are available online [66]. Similarly, the Citizen Science campaign "Plastik Piraten" offers school classes and youth groups the opportunity to actively support research into the nationwide contamination of plastics. Here, data collected by the students themselves can be made available to researchers for data evaluation. Furthermore, information, teaching, and working materials are made available free of charge on the project website [67].

Considering that plastic pollution is an emerging issue, there is a high need to build capacity of the future scientific and national authority staff in this area and address dedicated programs in student education and training, including bachelor, master, or PhD programs. After graduation, they will be familiar with the state-of-the-art techniques for sampling, extraction, purification, and analysis of plastic samples from water, sediment, and biota and, hence, become multipliers at the national and international level. Communication and knowledge exchange with nonacademic organizations, as well as with stakeholders involved in the plastic cycle, will facilitate contacts with potential future employers (e.g., industry, environmental agencies) while enabling them also to look for sustainable solutions.

An important program was launched by UN Environment, in cooperation with Open University of the Netherlands, the "massive open online course" (MOOC) on Marine Litter [68] aiming to teach students through action-oriented learning on how they can apply successful and inspiring activities to their own local context, regardless of their profession or location. The course introduces different options and tools to combat marine pollution; it provides examples and case studies to inspire leadership at all levels, thereby increasing awareness of and stimulating

creative solutions to marine litter problems. Moreover, the course supports policy makers, practitioners, and managers who wish to connect with other professionals in order to enhance their knowledge on marine litter issues.

A key fact regarding education nowadays is the possibility to use modern alternative digital tools to take over the role that traditional education can play. Social media are intensively used by the youth and reach better results in terms of accessing and acquiring knowledge than schools. Education materials on plastic impact, collection, recycling, and reuse should be prepared based on state-of-the-art research results and best available technologies in order to provide suitable tools to generate a behavioral change of the next generations.

Besides educating school children and younger generations, improving solid waste collection and management would also require targeting adult consumers' behavior, with this being especially true for developing countries and transition economies. The experience proves that this is an achievable goal, with formal and informal education activities generally increasing the public's understanding of the problem, fostering and inspiring better social and environmental solutions through positive examples and misconduct stigmatization.

3.3 Innovation

Innovation has a key role in paving the way for identifying solutions to the current challenges posed by plastic pollution, from observation, monitoring, and assessment of the contamination level to phasing out toxic components and designing environmentally friendlier materials to replace them.

A special focus is placed on designing remote macroplastic observation systems for seas and rivers. Macroplastic observation systems along the rivers could provide useful methods, for example, for the estimation of fluxes, retention, and inputs of litter into the seas, which is a mandatory step before planning adequate pollution reduction measures [69].

While preliminary steps have been made to monitor the flow of floating macroplastics using automated camera systems (Litter Cam) developed during RIMMEL project [70] or a device developed for seas during SPlasH! project [71], using remote sensors for rivers is more complicated due to the sediment transport and turbidity, which can induce high interferences in the accuracy. Hence, a series of parallel testing of analytical methods with sensor measurements should be performed to calibrate the sensors and eliminate the discrepancies.

In the SPlasH! project, the presence, origin, and dynamics of microplastics in several ports (Genoa, Olbia, Toulon) are analyzed. The study focuses not only on plastics floating on the sea surface but also on fibers present in the water column and on the seabed, providing data on aspects such as understanding the dynamic of microplastics and studying the influx and quantitative incidence of various sources of microplastics from land to sea, as well as their distribution at various depths in densely populated and active areas. The biological impact of microplastics is

analyzed by studying mullets, the most common fish populations in the ports. Further, the results will be combined with climatological trends to predict the trajectory of plastic debris dispersed at sea. The information will be disseminated to the general public by using multimedia tools and public initiatives and by directly involving economic actors and citizens.

The LIFE Preparatory Project in Support of the European Solidarity Corps (VISPO) [72] samples and analyzes the microplastic in the rivers Po in Italy and Danube in Hungary with the support of volunteers. Cleaning up the rivers from canoes and kayaks provides a unique experience of volunteering and training for young people under 30, through a first-hand contact with the nature and the issues linked with it.

In the project "Schone Rivieren" in the Netherlands, citizen scientists are studying the amount and quality of litter deposited on the riverbanks of Dutch rivers. In 2018, on 200 locations, almost 77,000 pieces of litter were found, of which 84% were plastic [73].

Innovation is also important to design environmentally friendlier substitutes of toxic plastic compounds and new decontamination methods of the sites impacted by plastic pollution. Also, a topic of increasing interest in recent years is developing innovative technologies aiming to valorize the plastic waste and create new materials. For instance, many applications target the use of plastic waste for building pavements or roads [74–76], for civil constructions and decorative products [77, 78], and for thermal insulation systems, solar modules, etc.

The management of plastic waste can also benefit from innovative concepts, such as from the "tokenized community," aiming to support management by blockchain technology, to create an economic environment that facilitates stable and transparent waste management and revalidation conditions, as well as functionality of the recycling value chains, thus ensuring sustainability in the long term.

Mostly the sustainability of revalidation chains (from waste to reused products) suffers from economic fluctuations, which make it difficult to have entrepreneurs taking an active role in recycling activities for low value mixed and contaminated waste fractions. Still most technologies are available to revalidate both high-quality (like PET bottles) and low-quality plastic waste fractions (like mixed food packaging films), but the economic viability is not there. Subsidies are needed to fill this so-called chain deficit and can be supported by governments or by private parties, e.g., in Extended Producer Responsibility schemes. In the present economic conditions, it is very difficult to predict where and when a chain of revalidation activities is profitable or not. Subsidies can support the decision to invest in the necessary technologies.

Traditional financing systems are mostly based on some sort of push financing, by paying an operator a certain amount of money to recycle or transport a specific amount of material. However, this requires an advanced control system to check whether the agreed operations have been really fulfilled. Moreover, they may not be available in every country.

A more promising concept is based on pull financing, where real activities are rewarded by tokens, which operate as a new currency within the revalidation chain and which are validated by both governments and funds from the EPR scheme of plastic suppliers, based on ecological results that have been achieved. This guarantees entrepreneurs that it is profitable to collect and revalidate even low-quality materials because their activities are rewarded in tokens, which later get a value from the government and EPR funds. The value of the tokens can be established at such a level that the required societal goals are effectively met.

4 Role of the Plastic Industry

The vast majority of plastic materials are produced by polymerization of hydrocarbon monomers. Plastics are used for highly diverse applications from, e.g., simple packaging to medical devices. To adapt plastic physical/chemical properties to the specific application, different additives are included during the manufacturing process.

Once produced, plastic materials enter into a cycle involving processors, distributors, collectors, recyclers, and convertors. For a sustainable cycle, all partners should consider options reducing the impact on the environment, minimizing the amount of generated waste and reducing energy consumption. However, this cycle closes only in seldom cases, as very often not all the plastic produced is recycled and reused, generating thus high amounts of waste.

Only in recent years, a special attention was given to plastic conversion (reuse) into new products such as clothing, bottles, carpets, etc. in order to prevent waste generation. Very promising are also the technologies to depolymerize plastics to monomers (chemical recycling) in combination with subsidies [79]. Exploring bottom-up initiatives to decrease pollution and a close cooperation of relevant stakeholders with the authorities may result in valuable recommendations addressed to industry and/or wastewater treatment operators to reduce the inflow of plastic substances in the aquatic environment.

Although the type of plastic material should be indicated by manufacturers, this is not always the case, and it can be misleading. Some synthetic polymers react to heat, and, hence, it is not recommended to heat food in plastic because harmful substances could be more easily released. Moreover, it is important to note that plastic does not seem to decompose in nature, just splits into small pieces, interfering with the biogeochemical cycles of the elements [49].

Selective collection and recycling of plastics is important, but cannot solve the problem of plastics alone. At present, only 9% of all plastics in the world have been recycled [80], while plastic production is rapidly increasing. Hence, it is recommendable to reduce the production and use of plastics by eco-design, consumption, and especially by reduction of single-use plastic products.

There are multiple ways the plastic industry can contribute to reduce pollution, such as:

- Designing new biodegradable plastic materials with lower impact on the environment
- Reducing the ratio and amount of plastic materials in new products
- Manufacturing products with a longer lifecycle
- Using recycled plastic and displaying the ratio recycled/new plastic on the product
- Developing incentives to stimulate collection and recycling of plastic products (EPR schemes)
- Implementing best practices for recycling – reuse of plastic products
- Improving plastic waste management and cooperating closely with other stakeholders to close the plastic loop
- Reducing the use of microbeads in cleansing products or abrasive substances
- Supporting plastic removal from the environment (polluter pays principle)
- Developing and implementing chemical recycling facilities for mixed and polluted plastic waste fractions
- Organizing knowledge sharing events to support exchange on best practices and know-how transfer, etc.

Considering the strong connection between the land-based pollution sources and the aquatic contamination, a close cooperation of the plastic industry with water and waste management authorities is needed to discuss challenges and adapt the plastic production and waste management plans accordingly.

One example of fruitful collaboration involving local stakeholders recently led to the testing phase of biodegradable polymers for the offshore mussel farming. In this case, lost mussel nets were identified as widespread in the marine environment, especially in the proximity of aquaculture facilities [81]. This led some companies specialized in the production of plastic gear for fishing and aquaculture to start developing mussel nets made of biodegradable polymers prepared from starch and bio-based polyesters. These innovative products are now being tested in collaboration with local fishermen and aquaculture plants within the framework of international European research projects such as Plastic Busters, ML-Repair, DeFishGear, and EU GHOST.

Another example is Fishing for Litter (FfL), an initiative that aims to reduce marine litter by involving the key stakeholders such as the fishing industry and mussel culture farmers. The initiative, now widespread in several European countries, foresees and facilitates the direct removal of litter from the sea, including abandoned or lost fishing gear and mussel socks, while raising at the same time awareness of the significance of the problem amongst the fishing community. It was originally started by the North Sea Directorate of the Dutch Government in cooperation with the Dutch Fisheries Association in March 2000. Pilot schemes were operated by KIMO International in the UK, Sweden, the Netherlands, and Denmark until 2005. Then the program was established in numerous other countries leading to the removal of substantial quantities of marine litter from the seabed [82].

5 Role of NGOs and the General Public

The general public has a leading role in the process of curbing plastic pollution: our options can make a difference, from the moment we decide to purchase a certain plastic product until the moment we dispose it and it is further taken up for recycling or conversion into a new product or at least for energy recovery by incineration. If we do care about the environment, we can select less harmful alternatives – all we need is the right information and education.

NGOs can contribute to this process by connecting different categories of stakeholders to provide adequate information, by initiating actions and mobilizing volunteers, by launching supportive projects, dissemination events, and awareness-raising activities, and by showcasing success stories and best practices to provide models to other communities – in other words, they can be the engine triggering a society response to decrease plastic pollution.

One of the most known examples is 5 Gyres [83], an American NGO working on plastic pollution research, who started to raise awareness about plastic distribution worldwide [84]. Every year, they organize dissemination activities and at least one citizen science expedition around the world, creating a global network of "ambassadors" raising awareness on plastic pollution.

The Ocean Cleanup developed advanced technologies to clean plastics from the oceans [85]. Their research on the Great Pacific Garbage Patch (GPGP) show that around 80 million kg of floating plastic debris have accumulated there, with microplastics representing the majority of the estimated 1.8 trillion pieces of plastic. It is estimated that the systems developed by this organization could clean up 50% of the plastic waste trapped in the GPGP every 5 years.

Clear Blue Sea uses an unmanned robot (FRED – floating robot for eliminating debris) powered by sun and wind to clean plastic waste from the marine environment and rescue animals trapped in debris [86].

Waste Free Oceans (WFO) works to reduce the global impact of marine litter [87]. By mobilizing fisheries, recyclers, manufacturers, and policy makers, WFO aims to reduce, recycle, and ultimately reuse marine litter, mitigating the impact on both the environment and natural resources. It works with companies, big and small, who want to send a clear message of intelligent use of resources and protect our ocean environments. WFO partnered with the green cleaning brand Ecover and manufacturer Logoplaste to combine plastic trawled from the sea with plastic made from sugarcane and recycled plastic, in what was hailed as a world-first for packaging. Ecover used the launch of its Ocean Bottle washing-up liquid to highlight the long-term dangers of dumping plastic in the sea (Fig. 8).

WFO is currently expanding into a new area. The organization collects plastic from the ocean and rivers, mixes it with plastic collected from land, processes it into a plastic plant, and converts it into panels. These panels are used to build affordable houses/shelters for the local communities who have lost their homes in natural disasters, therefore contributing to the welfare of the population in the less fortunate areas [87].

Fig. 8 Ecover bottle developed by WFO from recycled plastic. Photo credit: Letitia Florea

In 2018, the organization launched a cleanup project in Bulgaria, having collected about 20 tones of PET from the riverbeds during various actions [87]. The project continued also in 2019, in close cooperation with major international partners, local authorities, companies, NGOs, and other stakeholders, aiming to increase the number of cleanups organized in the Danube basin. In relation with national and international recycling companies and leading European plastics converters, WFO will use as much as possible of the collected plastic debris, turning it back into new products. The goal is not only to contribute to being part of an end of pipe cleanup but to be actively involved in prevention while inspiring local and regional entrepreneurs to engage and further invest in recycling technologies, in line with the EU Circular Economy.

Another project aims to contribute to the prevention and the cleanup of plastics pollution in the Atlantic Ocean, by removing floating marine litter in São Miguel island and raising awareness of stakeholders, both policy makers and the public at large, by collecting information that documents the impact of marine debris, building the capacity of the project partners and supporting the mobilization of resources for a larger follow-up project that could cover the whole Azores area [87].

Waste Free Waters (WFW) is a Dutch NGO which launched a project in 2012 to clean the Meuse River from plastic waste in cooperation with regional and local authorities, water authorities, landowners, associations, environmental NGOs, and the general public. In a coordinated activity, the banks along the full stretch of the Meuse were cleaned yearly between March and May, with the involvement of all municipalities along the Meuse, communicating and facilitating most of the activities in their territories. This activity has spread

further to other rivers in the Netherlands, with hundreds of people being gradually involved. Consequently, the project was expanded and named "Clean Rivers," with numerous citizens being trained to monitor the presence of litter on the riverbanks [73].

Other NGOs such as Greenpeace [88], Friends of the Earth [89], Oceana [90], and Ocean Care [91] and networks such as Plastic Pollution Coalition [92] have launched public campaigns and petitions to reduce plastic pollution and are highly engaged in advocacy work to improve plastic waste management.

Citizen science plays an increasing role in raising public awareness on plastic pollution, as shown within SEACleaner project, a project involving students, NGOs, and Marine Protected Areas in Italy, devoted to monitor beach macro- and microplastic litter [93]. The evaluations have shown that students changed quantitatively their perception of beach litter causes and derived problems, and they improved their knowledge about the main marine litter sources and the role of the sea in waste transport and deposition along the coast [94].

Developing specific citizen science programs can foster their involvement in monitoring plastic pollution or for collecting samples to be further analyzed in specialized chemical labs. Moreover, following the example of the applications developed for the marine environment (e.g., EEA, Litterati, TrashOut), dedicated "apps" for the rivers should be created to acquire information about plastic pollution along the banks and water courses. By training citizens on using these apps to monitor and report plastic pollution to water management authorities, the information could be used to design proper intervention measures for cleaning water and river banks in critical sections.

Creating educational programs and field events for pupils and teens to raise their support for pollution reduction measures and nature conservation activities is another important measure to be taken, provided that young persons are more receptive to environmental problems. This can contribute to induce a behavioral change for the young generations, as they will be aware of the risks posed by plastic pollution to human and wildlife health and can positively influence their networks.

The societal research and interviews made obvious that there is a lack of scientific knowledge among the citizens, and people are not aware about their roles as stakeholders involved in the plastic cycle. Based on these facts, a practical education model was developed using leisure and nature-related activities and selecting well-known and respected people to play role models to the different generations [95].

A very good inspiration can also be provided by local youth initiatives, such as #FridaysForFuture, which started in August 2018 when a Swedish 15-year-old girl Greta Thunberg protested for 3 weeks against the lack of action on the climate crisis. She posted images of her strike on Instagram and Twitter, and it soon went viral. The hashtags #FridaysForFuture and #Climatestrike spread, and many students and adults began to protest outside of their parliaments and local city halls all over the world, inspiring youth from over 140 countries and addressing world leaders at the UN conference on September 23, 2019 [96].

Education and awareness in our lives is crucial. If more people will start selecting carefully plastic products they use or the way they dispose it, the public behavior will gradually change, triggering a significant reduction of plastic pollution.

6 Communication and Awareness Raising

One of the most effective long-term measures to reduce plastic pollution is to significantly raise awareness of the society on the benefits of reducing plastic pollution for the environment and human health and trigger a shift of the current consumer behavior. By mobilizing support of major stakeholders, innovative solutions could be identified to improve collection/recycling systems, incentivize plastic reuse, reduce contamination at the source, secure circular management of plastics, change plastic composition, and replace harmful substances with environmentally friendlier compounds, etc.

Key messages should be addressed to different target groups, including high-level policy makers, waste management authorities, environmental protection agencies, plastic and cosmetic industry, wastewater treatment plant operators, economic partners, local authorities, research organizations, education units, NGOs, etc. Social media campaigns explaining the risks of plastic pollution, emphasizing impact on wildlife and human health, and informing citizens on simple ways to reduce it should be launched in parallel to increase the public outreach.

Awareness-raising activities need to involve the scientific community, considering that this can provide sound state-of-the-art information on the most frequent occurrence of plastic compounds and the risks they pose to wildlife and human health. Based on scientific results, recommendations concerning possible ways toward reducing plastic pollution in the aquatic environment should be prepared for decision-makers (water and waste management authorities, environmental protection agencies, river basin commissions, funding agencies, etc.), stakeholders involved in the plastic cycle, NGOs, and the general public in order to ensure a wider uptake of the key messages. Such recommendations can act as a catalyst for changes in policy development and implementation by providing and disseminating solutions and best practices to reduce plastic pollution at the wide regional level.

Experience sharing and knowledge exchange between local authorities and stakeholders involved in the plastic cycle (production, distribution, collection, recycling, reuse) have also an important role to foster identification of sustainable measures to reduce plastic pollution and multiply positive examples. Dissemination of good practices and knowledge transfer can be fostered, for example, via field visits to successful stakeholders involved in the plastic cycle, to showcase “live” examples on how various plastic products such as PET bottles, fishing nets, fibers, and rigid plastic waste can be transformed into high-quality raw materials. Such visits can accelerate replication of positive experiences and contribute to the reduction of pollution in new regions.

Events like science festivals and exhibitions, science books, and plastic cleaning activities also contribute to raise the awareness of people, supporting also the achievement of the United Nations Sustainable Development Goal 14 to "conserve and sustainably use the oceans, seas, and marine resources for sustainable development." With increasing ocean literacy in the society, the economic stability and security can be improved, supporting at the same time the society to understand critical issues associated with ocean-related topics such as ecology, trade, energy exploration, climate change, biodiversity, the link between ocean and human health, etc.

Interdisciplinary work, bridging different disciplines such as arts, sciences, humanities, and social sciences (Fig. 9), can also be very effective in tackling problems such as plastic pollution, with the integration of a diverse range of disciplines generally producing augmented consensus and fruitful synergistic solutions [97].

Social media campaigns play a crucial role in raising public awareness: TV, radio, Facebook, and Twitter, – they all have the possibility to reach people at broader scales, and, hence, they can mobilize wider support to curb the current pollution trends.

NGOs contribute to communication and dissemination activities by writing science books and articles, attending festivals, exhibitions, presentations, conferences, projects, TV shows on the environment, cleaning up events, and expeditions, giving interviews, education activities-school programs, and citizen science projects.

Fig. 9 Teaching future teachers about plastic pollution at Zuyd University, Netherlands. (Photo credit: Gijsbert Tweehuysen)

Within the framework of, e.g., LIFE VISPO project run by ERI, partnerships with schools, NGOs, public and business organizations, and media were developed to promote the initiatives for reducing plastics in the aquatic environment and raise attention to the stakeholders' role against pollution. A successful example for local initiatives is to be present on sport events and reach out to a larger audience who uses nature for leisure activities. This is how people from different age groups were interviewed, leading to the conclusion that most people are not aware of the plastic impact and ways to reduce plastic pollution by simple actions.

7 Conclusions: The Way Ahead

Generated in the last decades by the development of human society, plastic pollution extended gradually across the globe, turning into a significant threat to wildlife and human health.

Preliminary investigations of the impacts triggered by plastic pollution show alarming results, and, hence, urgent actions are needed to curb the pollution trends. While the stakeholders involved in plastic management can improve their cooperation to close the plastic production-reuse loop in a circular economy approach, there are also connected fields that could have an essential contribution, such as research and innovation, education, awareness raising, etc.

However, the biggest change should take place at the societal level, where multiple choices are possible to reduce plastic pollution by simple changes of the daily habits:

- Reducing the use of single-use plastic products (bags, bottles, cups, plates, food packaging, straws, etc.)
- Reusing plastic products
- Repairing, sharing, or renting devices incorporating plastic
- Supporting plastic recycling by selecting and disposing plastic waste at appropriate collection points
- Participating in actions aiming to clean plastic waste
- Selecting products from manufacturers with a higher recycling rate
- Shopping directly at local or farmers' markets to avoid unnecessary plastic packaging
- Reducing purchase of products incorporating microplastics
- Opting for promotional gifts, bags, bottles, etc. made of biodegradable products
- Buying items made of natural materials, giving preference to eco-friendly items

Reducing plastic pollution therefore requires a concerted effort from all of us – and with minor behavioral changes, we can all contribute to curb the current pollution trends and have a healthier environment.

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Education Against Plastic Pollution: Current Approaches and Best Practices

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Contents

Abstract Plastic pollution has been a topic of major concern not only for the scientific community. In the past decade, science has been instrumental in drawing attention to the issue of plastic pollution on land and in the ocean and its far-reaching implications for the health and the well-being of the biosphere. Using scientific data and findings, a whole suite of stakeholders have been developing approaches to address this issue. Along with other societal institutions, education has reacted to the presence and wide acknowledgment of the plastic pollution challenge we are currently facing on a global scale. This work analyzes selected examples of educational programs on all levels of education. We review the initiatives we have found from primary to tertiary levels of formal education and go beyond the scope of the formal system to see how informal education has reacted to the plastic problem.

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The goal of this analysis is to see the types of current educational projects worldwide to educate students of various age groups about plastic pollution. We also attempt to see if there is anything missing from the big strategic picture of education as a tool to address plastic pollution on land and in the ocean.

Keywords Environmental education, Environmental initiatives, MOOC, Plastic pollution, Sustainability education, Waste education

Abbreviations

EQ	Emotional quotient
IQ	Intelligence quotient
IUCN	International Union for Conservation of Nature
MOOC	Massive open online course
NGO	Nongovernmental organization
SDGs	Sustainable Development Goals
UNEP	United Nations Environment Programme
WWF	World Wildlife Fund
3Rs	Reduce, reuse, and recycle

1 Introduction

Education is widely recognized as key to changing the processes and attitudes in society. It plays a central role in addressing the complex issues that we as a global society are faced with. Nelson Mandela, the renowned South African political activist and philanthropist, is reported to have referred to education as "the most powerful weapon which you can use to change the world."

Education is a critical tool in helping people at all age levels to participate fully and responsibly in the global attempt to mitigate and tackle the environmental crisis. It does so by providing people with the new mental models, knowledge, and sets of skills, which altogether make up the competence to participate, deliberate, and analyze the pools of data available and come to conclusions based on this data.

Education has an immense capacity of not only informing people of the reality around them and providing them with data and skills to manage that reality but also acting on a deeper level and changing mindsets and attitudes. Ideally, it enables students to develop and use critical reflection, observation, and careful analysis to evaluate ideas, problems, and policies.

All of the above is the reason that education is an inherent part in every sustainable development strategy and model and is Goal 4 of the 17 Sustainable Development Goals (SDGs) set by the United Nations organization in 2015 [1].

To take one such example of a sustainable development model, apart from the global United Nations organization's agenda, let us consider the "doughnut" by Kate

Raworth, "the doughnut of planetary boundaries and social boundaries," which defines "a safe and just space for humanity to thrive in" [2]. This model combines the nine planetary boundaries set out by Rockström et al. [3], beyond which lie environmental degradation and crises in Earth systems [4], with an overlying social layer. One of the 11 top social priorities identified by the world's governments in the run-up to Rio+20 – and still remaining that – is education.

Education can have a vast impact on the learner and, therefore, on the whole society. One of the undebatable improvements in modern education is its much wider accessibility, compared to the past, due to the technological and social advances. At the same time, the more widespread and accessible education is, the more importance has to be given to it as a tool to share the skills, knowledge, and values necessary for sustainable development of our society and care for the environment as a crucial part of its well-being.

In 1991, the International Union for Conservation of Nature (IUCN) together with United Nations Environment Programme (UNEP) and World Wildlife Fund (WWF) developed *A Strategy for Sustainable Living*. This publication already stressed the utmost importance of "a new approach to build understanding of human relations with the natural world into formal education" [5]. This was defined as critical to changing personal attitudes and practices. The authors underlined that formal education "should not only be provided more widely, but changed in content." Students of all ages should be schooled in both knowledge and values that would allow them to live more sustainably. Such a goal, according to the authors, called for introducing environmental education at all levels of the formal educational structure. At the same time, a big accent was made on the part that non-formal education and communication play in people adopting the ethic and the necessary set of skills and knowledge for sustainable living. Thus, the non-formal educational element was already recognized to be of equal importance with the formal one in teaching sustainable thinking and habits.

The purpose of this chapter is to give an overview of educational efforts undertaken by a variety of stakeholders on a variety of levels all over the globe. The list of the initiatives presented in this chapter is by no means exhaustive due to the sheer scope of the task. Therefore, it should not be taken as a complete catalogue of the world's educational projects in the area of plastic pollution. For instance, there is such an impressive amount of curricula and both indoor and outdoor lesson materials on plastic pollution developed by organizations worldwide, that it would not be feasible to list them all in a concise overview. For this reason, for the purposes of the publication, we will only provide a number of examples of such initiatives.

The goal of this work is not only to present the projects actively engaged in plastic pollution education but also to systematize these existing and emerging efforts, in accordance with the type of the educational activity in question and the stakeholders engaged.

The data for this research has been collected by means of a thorough study of the practices, projects, and initiatives led by the international environmental and marine litter research and action communities. The result of the survey conducted is presented in this chapter as a system of educational efforts, broken down into formal

and non-formal educational projects undertaken by a variety of stakeholders for learners of different age groups.

2 Types of Education

It is beyond the scope of this overview to go into detail of what education is and which levels it comprises, but a brief mention of the types of education would be helpful for a further overview of the educational efforts taken across the globe to tackle plastic pollution of the environment.

The three currently recognized types of education are formal, informal, and non-formal. However, there is a significant amount of debate over the distinctions between those, particularly between non-formal and informal education, which are contested by various education researchers, resulting in a number of competing definitions. For the ease of our analysis, we will reduce the existing variety of the types of education, as well as their definitions and interpretations, to formal and non-formal.

Formal education is "institutionalized training, which represents compulsory education and ends with a specific certification of acquired skills" [6]. In essence, this is a system of formal education institutions providing compulsory education in a country.

Non-formal education and training are all educational programs and initiatives placed outside the formal education system. Non-formal education is "intentional, the person attending these forms of education makes it for own reasons, and programs are organized for learning, coming to complement, support or as a source of valorization of the learning experiences formally acquired" [7].

These are the two types of education that we will focus on for the purposes of this overview. Informal education does not fall within the scope of our analysis, as it is not a deliberately organized set of activities, but rather an unintentional learning process gained in the course of any activities, without the learner setting a goal to learn something. Informal learning is just as important in acquiring the set of skills and knowledge needed to tackle any sustainability issue, including pollution. This type of learning takes place while volunteering, doing cleanups, and participating in all kinds of environmental community and citizen science projects that deal with pollution, without an immediate goal to learn something, but a drive for action and result instead. The kind of knowledge obtained that way is critically important, as it by definition comes in a set with the understanding of how to apply it. Nonetheless, since this chapter is dedicated to education, which always has a clear educational goal, informal education will remain out of this analysis.

3 Formal Education Initiatives to Tackle Plastic Pollution

3.1 Environmental Education According to A Strategy for Sustainable Living

A Strategy for Sustainable Living laid out a certain amount of actions that are needed to be taken by governments on different levels to achieve sustainability [5]. One of those actions was reviewing the status of environmental education, making it an integral part of formal education at all levels: primary, secondary, and tertiary. The *Strategy* pointed out that while some special environmental courses were needed, especially at the tertiary level, it was most effective to incorporate environmental themes in other courses to show how sustainability and environmental protection are interconnected with the reality around us rather than being a separate topic to think about within a separate course. The authors of the *Strategy* also suggested that in the longer term, environmental education had to become a standard part of teacher training. It is therefore particularly interesting to see what initiatives have appeared in the field of formal education since the moment these recommendations were laid out and find out whether any of the latter has been implemented.

3.2 Programs for Primary and Secondary Education Levels

3.2.1 School Curricula and Educational Packages on Preventing Plastic Pollution

Taking a look at what is happening at schools, from the very first grade and primary level to high school curricula, the variety of programs educating students about the plastic pollution and engaging them in the issue is astounding. This level of learning comprises by far the biggest diversity of environmental educational efforts that we found. This can be explained by the necessity to develop a responsible attitude to nature and one's own consumption habits starting from the very childhood, as it can become quite challenging to do that with adult audiences.

Happy Green World is a Netherlands-based environmental educational foundation, which develops educational programs about waste, water, and energy to teach sustainable behavior to children between 6 and 12 years [8]. To that end, the foundation, launched in 2011 in Cairo, Egypt, has developed several educational packages revolving around three topics: waste, energy, and water. A package consists of an activity guide for the teacher, a student book, and a game, all of which focus on practical activities around the 3Rs. There are 31 activities in the guide. The teacher has the autonomy to decide which of the suggested activities suit their students and subject best, as well as how much time during the class they prefer to allocate for a given activity. All activities suggested in the guide are split into three types: awareness activities, thinking activities, and doing activities. The awareness

activities serve to make children aware of what waste is and how it can be reused and recycled. Thinking activities use a mind mapping method to get students to brainstorm solutions for the issue of waste. Doing activities are about practical actions, such as cleanup, recycling, or composting workshops. The student book, in its turn, contains structured information on how to avoid generating waste and reuse the materials that can be used in daily life. Students also learn the basics of green urban practices. Finally, the game allows students to put to practice all the knowledge obtained in an interactive way while also learning the principles of teamwork.

Green Indonesia is an environmental program developed by the Indonesian Waste Platform for primary and junior high schools in 2013 [9]. The program is introduced to Indonesian schools by 2-day teacher trainings in collaboration with education departments of local governments. The materials used by this project were co-developed with the Happy Green World Foundation and thus follow the structure and the logic described above. However, there are some unique features about this program. They are based on the premise that educating children about the importance of preventing waste in the environment and encouraging them not to litter or generate unnecessary waste must go hand in hand with the establishment of local waste infrastructure. Otherwise, all education and knowledge might remain on a purely theoretical level or clash with the existing realities. To avoid that, Green Indonesia developed and implemented the concept of school waste banks, which function as recyclables' collection points both for the school students and local communities. This was made possible by collaboration with ADUPI, the Indonesian Plastic Recycling Association, which serves as a link between schools and the recycling network of Indonesia. The program started on the island of Flores and has collaborated with the Ministry for Maritime Affairs and Fisheries of Indonesia to bring this training to schools on several other islands of the country (Fig. 1).

There are currently two initiatives in the Russian Federation that bring waste education to schools. Center for Saving Resources, an environmental training and consulting project, has developed a range of environmental school classes, a couple of them dealing directly with the issue of waste and preventing plastic pollution [10]. The Center employees deliver these classes in Moscow schools upon their request. The Center has also developed free, open access educational materials and guidebooks for Russian teachers who would like to bring up the waste issue in their classes.

Another Russian initiative to tackle the issue of plastic pollution, among other environmental issues, is a project called Taiga [11]. Since 2016 it has developed educational activities for school students of all ages, as well as senior kindergarten classes. Depending on the students' age, Taiga offers a variety of formats to speak about the implications of plastic presence in marine and terrestrial ecosystems, waste generation and prevention, and values and attitudes to the environment that underlie our consumption habits. These formats include a board game on recycling, which teaches children the principles of recycling and waste separation, interactive workshops on plastics in marine ecosystems, and classes on daily habits and consumption patterns (Fig. 2). Taiga also explores outdoor education formats, such as

Fig. 1 Training for junior high school teachers in subdistrict Komodo by Green Indonesia as part of the Ministry's campaign Garekan Cinta Laut in 2017. Photo credit: Nina van Zinnicq Bergmann [9]

Fig. 2 Cards from the recycling board game developed by Taiga, Russia: plastic fork, plastic bottle, plastic straw (left to right)

environmental scavenger hunts and workshops at summer camps to teach children about the plastic pollution issue.

There is an impressive variety of organizations and initiatives all over the world reaching out to classrooms to teach children about the issue of marine plastic

Fig. 3 Plastic Punch giving a school class on plastic pollution in Accra, Ghana. Photo credit: Richmond Kennedy Quarcoo

pollution and how their personal habits can have an impact on the issue. Aulamar, an educational initiative from Uruguay, came to schools to teach the school students outdoor classes on marine pollution on the local beaches. The students sampled sand for plastic particles, learned to use protocols for sampling procedures, observed and registered pollution, and then learned what they could do to change what they were observing. The project team made an important observation – such classes and discussing such topics with the children raise not only their IQ but also their EQ [12].

Plastic Punch from Ghana comes to schools to talk about the life cycle of plastic products and the sources of marine pollution. Plastic Punch complements discussions within classroom walls with beach cleanups in Accra to have students experience the scale of plastic pollution firsthand [13] (Fig. 3).

One More Generation (OMG), a nonprofit organization aimed at environmental conservation, offers a number of educational programs for schools in the USA. The project developed a Plastic and Recycling Awareness Week school curriculum, which matches with the latest National Science Education Standards and can be used with students aged 5–12 [14]. The curriculum is a detailed lesson plan for 5 consecutive days of the program available for free electronically. It applies tools of science, art and language to speak about careful use of resources, the power of sustainable daily habits, and recycling principles. Since the Plastic and Recycling Awareness Week was developed in 2012, over 300 schools across the USA have successfully completed the program. Several schools made it mandatory for all students coming into their school each year to complete the weeklong curriculum.

Three more examples of integrated curricula developed in the USA around plastic pollution and its reduction are Marine Debris STEAMSS, Integrated Plastic Pollution Curriculum, and Washed Ashore's Integrated Arts Marine Debris Curriculum.

Marine Debris STEAMSS was created by Oregon Sea Grant in partnership with Oregon Coast Aquarium and Lincoln County School District [15]. The partners structured existing and new curricular materials relating to the topic of marine debris for grades 4–12. Integrating the subject areas of Science, Technology, Engineering, Art, Math, and Social Studies (STEAMSS), the curriculum focuses on experiential, hands-on activities in the classroom and in the field. Lessons are grouped into three grade bands of upper elementary, middle, and high school. Lesson materials are grouped into four categories that scaffold understanding of the issue of marine debris: composition and abundance of marine debris, sources and transport, impacts, and solutions. The lessons also include opportunities for students to address problems through engineering design, to use technology and art to effectively convey stewardship messages, to contribute to cleanup efforts, and to work with community partners.

Integrated Plastic Pollution Curriculum brings together scientific, political, social, and economic lessons through hands-on activities and student-led projects. Along with regular teacher training sessions, class presentations, and free reusable teaching kits for middle and high school students across Southern California, USA, it is available through Algalita Marine Research Foundation [16].

Washed Ashore's Integrated Arts Marine Debris Curriculum, developed by the Washed Ashore Project, is based on the belief that it takes a combination of science and art to change the world, since innovative solutions come from creative and intuitive parts of the human brain. The 12 lessons of the curriculum, designed for fourth through sixth grade students, bring together art and science to help students understand plastic pollution and communicate about it using the language of the arts [17]. Core competencies in science, writing, visual arts, and social studies are part of the lessons to enable the curriculum to cross subject boundaries.

There are numerous other school curricula on plastic, its abundance, and pathways in the environment, such as the ones developed by a nonprofit organization EarthEcho International [18], but for the purposes of this analysis, we shall move forward to other formats of educational impact relevant to the plastic pollution issue.

As we have already seen, not always the teacher possesses the necessary expertise and knowledge of the issue to be able to teach it to their students. Consequently, in the absence of this expertise, knowledge transfer mechanisms are critical to raising a generation that will be aware of the issue and have the set of habits, values, and solutions necessary to tackle it. One such mechanism is open access materials and curricula, some which were reviewed above. However, for the situations when a teacher is not able to teach about the plastic pollution issue using either their own knowledge or the available materials, tools for engaging external experts become an important part of sustainability education.

Our next example of an educational initiative addressing the plastic challenge also comes from the USA and is a series of classes on plastic pollution of the ocean through a web-based solution called Nepris. Nepris is a platform that connects school teachers with industry experts to enrich the curriculum with hands-on

experience from scientists and practitioners and demonstrate real-world applications to what students are being taught in class. The mission of the project is to help expose students to the variety of the career paths that lie ahead of them, focusing on STEAM (Science, Technology, Engineering, Arts, and Math) fields. Both school teachers and industry experts are welcome to register on the platform and indicate their area of interest or expertise. A couple of California high schools expressed interest toward the issue of plastic pollution of the ocean via this platform and requested volunteer experts through the platform to share their research and answer some questions the students had already collected [19]. This effort demonstrates not only commitment on the part of the scientific community, which often does this kind of educational work on a voluntary basis, but also an explicit interest on the part of school students toward the issue of plastic pollution.

This connection between the students interested in learning more about the issue of plastic pollution and the experts to share their knowledge does not necessarily have to happen through a project or a web platform. There are examples of marine debris experts reaching out to classrooms on their own. Veronica Padula, a marine debris researcher from Alaska, USA, shares her experience to discuss the issue and talk about her graduate research on the impact of fishing gear on seabirds of the Bering Sea. Veronica emphasizes her finding: of all educational interactions with various communities of the entire state, the more personal ones had the greatest success. According to Veronica, these more personal interactions with interested groups not only are a very efficient way of conveying one's passion for the healthy environment and its preservation but also present a valuable opportunity to build partnerships and relationships with communities and learn about new perspectives on how marine debris impacts these communities [20].

The educational efforts we discussed above were all initiated by either nonprofit organizations, start-ups, or even individual researchers. Parts of them to some extent have governmental support. However, they still are grassroots projects that may grow so popular in a given community that the official education or natural resources authorities will decide to support them.

3.2.2 Governmental Educational Initiatives on Plastic Pollution

As opposed to this bottom-up approach, there are also a number of top-down initiatives on the ministry level, although these clearly represent a minority of current initiatives combating plastic pollution.

The Federal Ministry of Education and Research of Germany (BMBF) launched an initiative called Plastic in the Environment ("Plastik in der Umwelt"), which encompasses 20 nationwide research projects, looking at 5 major facets of the plastic pollution issue [21]. These are green economy, consumption, recycling, and limnic and marine ecosystems. The goal of the overall initiative is to substantially reduce the presence of plastics in the environment by advancing scientific research in this field and bringing together science, politics, and industry to interact and develop

joint solutions. Importantly, for the long-term transfer of knowledge from the 20 research projects, there are project weeks at schools and universities across the country, as well as other educational efforts that will be mentioned in further sections.

Apart from these weeks, designated for raising awareness among school and university students and providing them with the latest research data, there is also a project called the Plastic Pirates ("Plastikpiraten"). It is aimed at middle and high school students aged between 10 and 16. On our "map" of educational projects on plastic pollution, this initiative would best be placed at the junction between school education and citizen science [22]. School students across Germany in groups collect data on the amounts of plastic litter in German waterways and water bodies and try to establish the patterns of plastic pollution that they see. Participants register all macro- and microplastic objects and particles they come across and contribute this data to the countrywide plastic pollution map [23]. The data that students thus collect is then used by a research center in Kiel for a deeper analysis. This is done to see, for instance, which parts of rivers are the most polluted and how pollution spreads down the river and in the water column. The data collected in the course of the Plastic Pirates project is crucial to develop appropriate water body protection and pollution prevention measures. Hence, the research activities of participants not only are of a high educational value but also contribute to the current research and conservation efforts.

We consider the Plastic Pirates project by BMBF to be a brilliant example of student engagement and motivation. Youths tend to feel powerless to impact the issues around them. Very often, when they are taught about environmental issues, such as plastic pollution, they do not have a lever to make any impact other than reconsidering their personal choices, if that is an option. By contrast, projects like Plastic Pirates not only teach youths the basics of a scientific approach to research but also validate their project work by making it an essential part of developing a pollution mitigation strategy.

National Oceanic and Atmospheric Administration (NOAA) of the US Department of Commerce have developed a whole array of free educational materials on plastic pollution for the educators. These materials come in a wide range of formats – coloring books, puzzles, brainteasers, formal curricula, and marine debris monitoring toolkits – for grades 1–12 [24].

The Ministry of Education of the Netherlands has launched a Healthy School program that marks participating schools of the country with a special vignette – a quality mark attesting that the school works to improve the health of its students [25]. The program is built on the basis of four pillars, each of which has to be implemented if a school is interested to obtain the vignette. These pillars are Education, Signaling, School Environment, and Policy. What makes it relevant to the subject of educating school students on plastic pollution is that three out of those four pillars directly address environmental issues, including pollution. For instance, the Education pillar requires that the school should incorporate environmental awareness in the curriculum and devote structural attention to it. The educational activities in the field of Environment and Nature are to be laid down in a school

policy plan, and teachers are to get an in-service training in that field as well. The School Environment pillar states that the school is responsible for a healthy environment around it. To illustrate, it is expected to be environmentally conscious, save energy, separate waste, and engage students, their parents, and employees in activities related to the environment and nature. Moreover, the very layout of the schoolyard should already engage students with nature, while the school staff is to set a good example in sustainable practices and habits.

The Ministry of Education of Belgium is implementing a similar concept. They developed a MOS program that helps make schools environmentally friendly and sustainable by providing them the necessary consultation, guidance, and regular training sessions [26]. The school can register as a MOS ("milieuzorg op school" in Dutch – "environmental care at school") school on the countrywide map or go further and become a certified eco-school. The Environmental Training and Education Service organizes various forms of training courses and study days for education professionals on environmental education and sustainable development, training them to incorporate sustainability topics into everyday classes for children from nursery to high school sessions.

The examples from the Netherlands and Belgium seem to be the closest to the goals that were set back in 1991 in *A Strategy for Sustainable Living*. These initiatives incorporate environmental education and action into the school curriculum as well as the daily life and provide school teachers with necessary training to be able to teach and engage their students by activities and by setting their own example in sustainable daily practices.

From the numerous examples we have analyzed, most schools still rely on a variety of external stakeholders to teach their students about plastic pollution. Such stakeholders, as we have seen, can be nonprofit organizations, various environmental start-ups, activist groups, individual researchers, or research project scientists, who will come to a school with a talk and develop activities around the plastic pollution issue, helping teachers diversify the curriculum and bring in the knowledge about real-world issues outside classroom walls. However, this scheme is imperfect. The coverage of the issue of plastic pollution that it provides is mostly patchy, limited to the time of the talk and the activity that the guest lecturer gives. If teachers, who are the backbone of a school and who interact with their students on a regular basis, have no real understanding of the issue, they will not be able to sustain this knowledge after the lecture or activity takes place, much less translate it into action or deeper reflection leading to reconsidering one's own habits and mental models. This is the immense value of environmental education at school – it shapes the mental models that will result in sustainable habits and practices for life. This process can hardly take place after a single talk, since this is a long-term process that needs to be supported by the entire environment in the school and outside it.

To coherently deliver the message on the importance of tackling plastic pollution, the school also needs to refuse single-use plastics, most of which is used in the cafeteria, as well as have water fountains and recycling infrastructure available where the plastic waste cannot be avoided. Otherwise, the message is bound to cause an internal conflict, where a student hears about a grave issue, and is inspired to help solve it, but not only has no opportunity to do that – the entire reality around

them is proving quite the opposite. In our experience during an all-Russian convention of school students, the students unanimously responded that being taught about the waste issue and the need to avoid or minimize waste while having no sustainable alternatives or even basic recycling infrastructure available causes a deep internal conflict and makes one feel powerless and desperate. At the same time, the entire goal of school education is to empower young people and prepare them for the challenges they will deal with.

In this regard three initiatives that we have seen so far stand out: the Healthy School and MOS programs by the Ministries of Education of the Netherlands and Belgium, for incorporating environmental education in school curricula and making schools a sustainable environment, and Green Indonesia, for providing recycling infrastructure along with training schools on plastic pollution.

3.3 Tertiary Level of Education

Educational activities to raise awareness of the plastic pollution are carried out at higher education institutions as well.

The most direct way to raise awareness of plastic pollution among students is to engage them in plastic-related research. This is successfully happening at higher education institutions that are advancing plastic pollution research, with dedicated research labs and hubs and some of the leading plastic pollution researchers on staff. This list includes, but is not limited to, University of Plymouth and University of Exeter in the United Kingdom; Vrije Universiteit Amsterdam and Wageningen University in the Netherlands; University of Toronto in Canada; University of Georgia in the USA; and Far Eastern Federal University in Russia. Most of these universities have specialized research centers and groups, such as International Marine Litter Research Unit (University of Plymouth), The Exeter Multidisciplinary Plastics Research Hub (ExeMPLaR) (University of Exeter), Wageningen Marine Research (Wageningen University), Rochman Lab (University of Toronto), or the Jambeck Research Group (University of Georgia).

Remarkably, a quick Internet search shows that the list of universities supervising students' work on the issue of plastic pollution, rather short a decade ago, is growing rapidly, along with the public interest toward the topic. The sheer number of the search results for *plastic research university* proves that students all over the world have gained interest in different aspects of the topic of plastic pollution and want to do research in this field.

Any marine science conference will have a number of posters and presentations on the issue of plastics in marine ecosystems, since this is no longer a subject that only few people know and are concerned about. For instance, the latest YOUMARES conference for young marine researchers held annually in Oldenburg, Germany, allocated one of the two conference days to hear the research on plastics in the environment presented by young scientists [27].

Plastic and its life cycle in the environment are included in the curricula of such degree programs as environmental engineering, as is the case with the University of

Georgia in the USA. Saint Petersburg Electrotechnical University in Russia has introduced a Technosphere Safety Bachelor program, which gives students an in-depth knowledge of current recycling technologies and advances in material science [28].

Interestingly, not only environmental or marine science students can and should work on plastic pollution. Plastic pollution, along with the majority of other environmental issues, is a crisis of the entire system, encompassing environmental, social, and economic issues. Hence, it can and should be studied and brainstormed from a whole range of perspectives.

One remarkable example of incorporating plastics into a non-environmental curriculum comes from Delft University of Technology (TU Delft) in the Netherlands. Master students taking a course in System Dynamics and Policy Analysis with Dr. Erik Pruyt since recently use the plastic pollution issue for conceptual modelling [29]. The goal of the model, which was, in fact, an exam, is to teach students complexities around recycling and bioplastics and demonstrate the points in the systems where plastic leaks into the environment (Fig. 4). Dr. Pruyt's students developed a simulation model to look at how the amounts of plastic produced and consumed on a global scale, in combination with the knowledge of pollution patterns and points of plastic leakage into the environment, spread into the Earth's water bodies and waterways. The model is expected to be used for policy advice and illustrate the need for behavior change.

When we look at the changes that are taking place in tertiary education and that reflect the growing understanding of the need to address plastic pollution, we see that they have found their way beyond the curricula and the list of research topics that students can choose from. A major shift that is taking place at higher education institutions all over the world is a shift in the education environment, known as the green campus programs. The concept of a green campus is about embedding sustainability principles across the institution's daily operations and processes, teaching, and research. Green campus programs can be quite sophisticated, but all of them start with minimizing waste, introducing recycling, and often reconsidering the use of disposable items such as cups, cutlery, bottles, or straws [30].

There are so many green campus institutions around the world that it is beyond the scope of this publication to analyze them. It is important, however, to keep these programs in mind as a manifestation of changing approaches in education. These are mostly student-driven changes, as green campus programs tend to be student-led. An institution can work toward sustainability without formally complying with any standards. At the same time, such standards exist, for instance, the Sustainability Tracking, Assessment & Rating System (STARS) developed by the Association for the Advancement of Sustainability in Higher Education. Apart from sustainable dining and waste minimization, STARS covers academic courses, sustainability literacy level, campus life, employee education, additional courses, staff professional training in sustainability issues, etc. [31]. Another metric is UI GreenMetric World University Ranking, developed by Universitas Indonesia in 2010 to systemize the current condition and policies related to sustainability in universities all over the world and draw the attention of university leaders and stakeholders to environmental

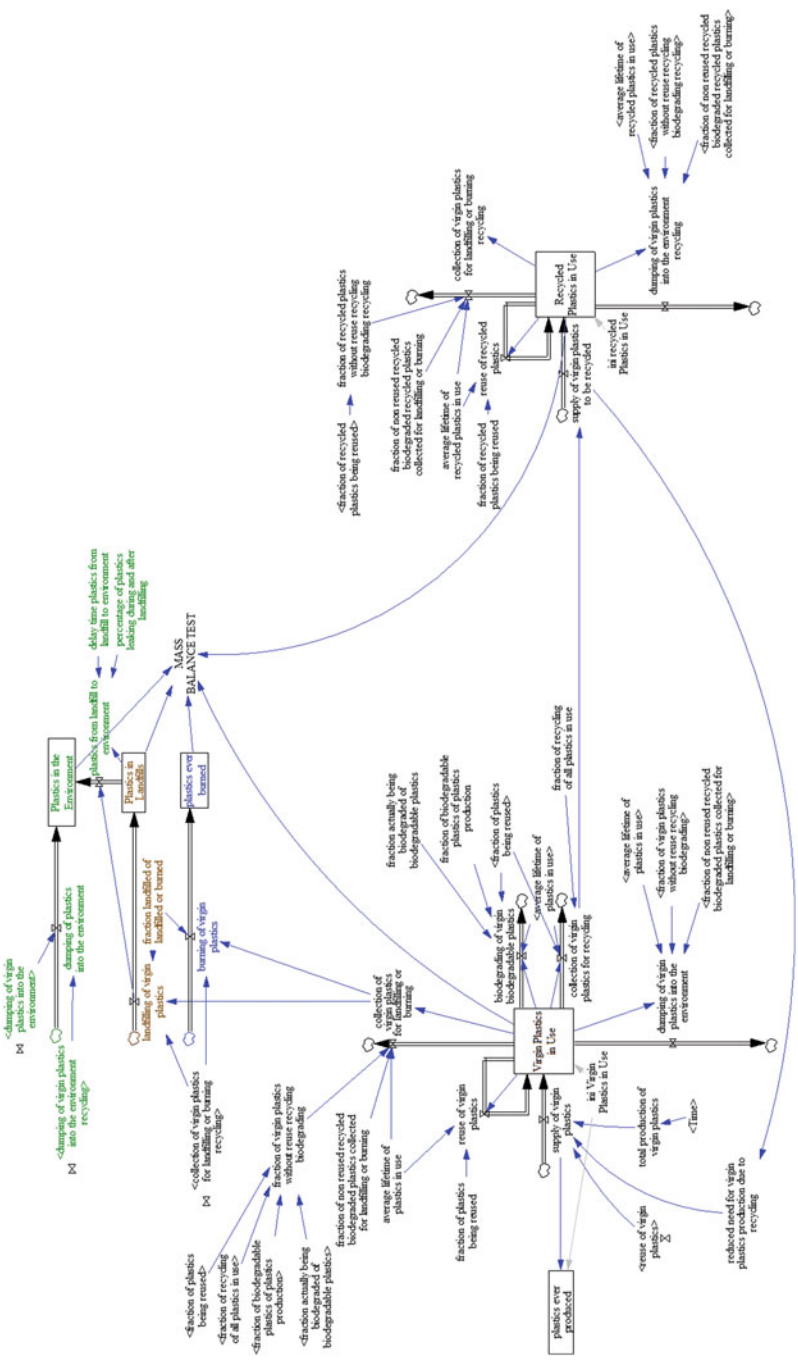

Fig. 4 A conceptual model of the plastic problem given as an exam to Master students in System Dynamics and Policy Analysis course at TU Delft [29]

issues, including the issue of waste [32]. There are numerous guidelines and recommendations available on how to set up a green campus, ranging from experience shared by other universities to governmental guidelines, such as Ecocampus developed by the Department of Environment of Belgium [33].

Without going into further analysis of the green campus programs and the multiple universities which have implemented them, we believe that such "green" changes in the educational environment are tightly connected with the changes in the education content toward more sustainability component. Therefore, we would also categorize them as an educational effort and include them here for the purposes of this overview.

Our next type of educational initiatives to raise awareness of plastic pollution will be extracurricular seminars and lectures delivered in universities around the globe. These can be one-time lectures or entire extracurricular courses delivered to all interested students. A good example of such an extracurricular course for students is a recent initiative at Vrije Universiteit Amsterdam in the Netherlands called a Broader Mind [34]. This is an educational initiative for enrolled Bachelor students of Vrije Universiteit, which teaches the students to apply their knowledge to solving pressing social issues and collaborate across borders. Part of the course has a focus on plastic pollution. The aim is to get university students to understand the nuance of the international plastic debate, as well as their own plastic behaviors, and do an online search to map inspiring examples from around the world. The program includes a plastic behavior exercise – students collect the plastic waste they have generated in a certain amount of time and bring it to the campus. There is also a consumer survey before and after the exercise to statistically assess the impact of the exercise on students' consumption choices. The pilot run of the course took place in 2019 and the course is now expected to run annually.

An interesting process currently happening in the field of formal education at all levels, as a reaction to the issue of plastic pollution, is incorporating non-formal education tools into a formal education process. We will touch upon these tools in further sections. The undoubted benefit of this novel combination is that it substantially increases the interactive component of the curriculum and enriches it with a deeper coverage of the topics in question. As we have already seen, both secondary and tertiary education institutions will often lack expertise on the waste issue, particularly on plastic, and thus have to resort to external expert knowledge. In a situation like that, incorporating readily available educational sustainability programs can be considered a good synergy between a formal educational system, with its compulsory learning process, and more interactive learning materials, which better correspond to the current pressing topics.

4 Non-formal Educational Programs and Tools to Tackle Plastic Pollution

Non-formal education, as we have already seen, can take many shapes and has a much wider audience, since there are usually no entry requirements and the entire educational process is much more flexible than formal education. Possible formats include courses, workshops, and educational events held on a regular or one-time basis to talk about plastic pollution. Big part of these programs is university-based – their content is developed by universities or in collaboration with them.

4.1 Massive Open Online Courses (MOOCs)

The first format to consider in this category is massive open online courses or MOOCs. They emerged as a format in 2006 and have become a popular learning approach, which many universities around the world use to share their research and complement their conventional curriculum. MOOCs are a revolutionary educational concept, whereby the course content is delivered online and free of costs to participants around the world regardless of their background. They are designed for unlimited participation and are open access for all participants who meet the only eligibility criterion which is to have internet connection [35].

A MOOC comprises traditional course materials, such as readings, assignments, and video lectures, and an interactive component, such as user forums, for the participants to be able to provide feedback on the material; analyze problems presented in the course; work in groups, if applicable; interact with each other; or form a community. A particular feature of MOOCs is that they encourage learner interaction in the form of discussion forums and threads, which is very often not the case in the formal approach. Each MOOC runs on a certain web platform, the technical capacities of which determine the kinds of tasks and interactions that will be possible for the participants of the MOOC.

Several MOOCs have included or have been entirely dedicated to the issue of plastic pollution. The MOOC on Marine Litter was developed in cooperation with the Open University of the Netherlands within the framework of the Global Partnership on Marine Litter and the Clean Seas Campaign and sponsored by the UN Environment Program [36].

The MOOC on Marine Litter was first launched in 2015, with a second round taking place in 2017. It was created “to stimulate leadership and offers opportunities for actionable and change oriented learning related to marine litter” [36].

The course increases awareness of marine litter problems and provides participants with insights and tools helpful in search for solutions and pollution mitigation strategies, such as case studies and interaction with stakeholder groups. Thereby, participants of the course can learn about various existing strategies to combat

pollution and connect with professionals and activists in this area to develop one for their local context.

The MOOC includes Leadership Track, which is 10 h of learning materials with the core knowledge of what marine litter is and what its main characteristics and impacts are. This track is geared toward policymakers and managers who require an overview of the topic to be able to incorporate the issue into their professional activities. The Expert Track is 30 additional hours with a final assignment for a more in-depth knowledge of marine litter and its prevention.

The Marine Litter MOOC covers such topics as sources and monitoring of marine litter; the environmental and socioeconomic impact of marine plastic pollution; the governance, policy, and law dimension of tackling marine plastic pollution; technical solutions to combat the pollution; and education and capacity building.

The Marine Litter MOOC thus presents the most comprehensive non-formal educational initiative in the field of marine plastic pollution, which is available to all interested individuals and is also used as a complementary teaching tool at over 530 universities globally. The course has been disseminated through the Global Universities Partnership on Environment and Sustainability (GUPES), which is a UNEP flagship program established in 2010, and aimed at increasing environmental commitment with higher education institutions around the globe.

One Planet One Ocean MOOC is a remarkably comprehensive MOOC developed in collaboration between GEOMAR, Helmholtz Center for Ocean Research Kiel, University of Kiel (CAU – Christian-Albrechts-Universität zu Kiel) in Germany, International Ocean Institute (IOI), and SDG Academy [37]. The purpose of the MOOC is to increase public understanding of the pivotal role of the ocean in almost all earth processes and the immense variety of services it provides us on a daily basis. This is achieved by providing participants with the basics of marine science and the complex processes taking place in the ocean systems.

This MOOC stands out with its holistic approach. It does not focus on any selected field of marine science. Instead, it provides a holistic overview of its different areas: marine biology, geology, ecology, and physical oceanography neighboring with maritime law, ethical and philosophical concepts of sustainable stewardship, and analysis of human impacts on the ocean.

The course is broken down into six thematic modules, covering an extensive range of ocean-related topics [38]. Plastic pollution of the ocean is presented in a dedicated unit in the module on Marine Ecosystems. It was specially developed for the 2018 run of the course, since plastic pollution has become such a pressing issue that it has to be addressed in a course on marine science and sustainability. The Unit includes two video lectures and further study material relevant to the problem.

The One Planet One Ocean MOOC was broadcast in 2016, 2017, and 2018, attracting over 9,000 participants from 62 countries. The 2018 version of the course also expanded the interactive component by adding three new sections: Blue Tips, Youth Engagement section, and Start-up Kitchen. The Blue Tip section brought a sustainable “blue” tip for daily life each of the 6 course weeks. Big part of those tips dealt with sustainable consumption patterns, such as going for natural fabrics only or sharing and repairing instead of buying new.

The Youth Engagement section weekly presented a young researcher or activist working on an ocean-sustainability-related topic. During their week the engager shared their expertise, gave interactive assignments complementing the main content of the course, and was available to answer participants' questions in the engagement section on the MOOC forum.

Start-up Kitchen presented in total five start-ups working toward ocean sustainability. Each start-up was given space to speak about their operations and goals, as well as interact with the course participants. Three of the five projects presented dealt with plastic pollution, and the fourth indirectly contributed to minimizing plastic pollution in India.

The 2018 run of the One Planet One Ocean MOOC addressed the issue of plastic pollution from a variety of perspectives, speaking about its origin and distribution, shedding light onto how our daily habits are linked to the problem and what solutions currently exist.

Exploring Our Oceans is a MOOC developed by the University of Southampton in the United Kingdom and FutureLearn platform, where it first ran in 2014. The 4-week course is also a comprehensive marine science course, covering the basics of oceanography, marine biology, geology, and ecology and bringing up plastic pollution as a danger for ocean ecosystems [39].

To summarize, the MOOCs we have considered not only educate wide audiences on the plastic pollution challenges and approaches to deal with them but also enhance international cooperation, reach different stakeholders, and inspire participants toward action while providing them with the tools and insights to do so. This eventually contributes to forming a global network of actors engaged in combatting the plastic pollution issue.

4.2 Other Open Access Training Opportunities

Apart from massive online courses that we have briefly reviewed in the previous section, there are other open access training opportunities on the plastic pollution challenge. They might not be structured as a MOOC, but they also provide their participants with necessary knowledge and skills to deal with the plastic waste issue or teach about it.

An example of such a course is an Educational Pack, supplemented with a 4-week-long online training course within the Marine Litter in European Seas – Social Awareness and Co-Responsibility (MARLISCO) project [40]. MARLISCO was a project funded by the European Union for the duration between 2012 and 2015. It included activities by a consortium of members located in 15 coastal countries. The overall goal of this project was to raise public awareness, facilitate dialogue, and promote co-responsibility among different actors toward a joint vision for the sustainable management of marine litter across all European seas [41]. To that end, a whole suite of activities and projects were undertaken, among which were the development of an Educational Pack and an E-Learning Course around it, a

wandering Exhibition, a Best Practice Guide, an educational Serious Game, and Marine Litter Database and Brochures.

The co-created Educational Pack "Know Feel Act! To Stop Marine Litter," translated into 16 languages, is a joint project of the MARLISCO consortium, aimed at both formal and non-formal teachers and students to learn about the problem of marine plastic waste and take action against it [40]. The material was prepared for youths aged 10–15 and can be used by any interested stakeholder for educational purposes outside the formal schooling system. For the purposes of this work, we categorize it as a non-formal educational initiative.

For the duration of the MARLISCO project, the Educational Pack was shared with schools electronically, but schools were welcome to raise funds to produce it in hardcopies, in case those were needed. The Pack contains 17 activities, each comprising a learning activity and a worksheet for students. These activities can be applied separately or combined in clusters to meet the needs of the educator using them in class.

The Pack was also supplemented with a 4-week-long online training course to train teachers and motivate them to use the Pack with their students. The course ran four times between 2014 and 2016, engaged over 400 participants from all over the world, and had a high completion rate.

We find it important that the project was designed for both formal and non-formal education purposes and has been open access and readily available in a variety of languages. The fact that the Educational Pack was also coupled with projects such as an E-Training Course and a Best Practice Guide makes it a truly comprehensive effort to educate wide audiences about plastic pollution. This is testified by research, which indicates that the effect of all these tools in changing people's perceptions and attitudes toward the issue of plastic has been acknowledged as important [42].

Although the MARLISCO project ended in 2015, its materials are still being used. For instance, the Russian translation of the Pack was completed in 2019 by a Russian NGO Friends of the Baltic for use within the Russian Federation.

Non-formal education is critically important for the change of perceptions and behaviors in a society. Being much less formalized and more interactive than formal education, it has the flexibility to respond to the current pressing issues much faster than school or university curricula. Therefore, we see a lot of benefits in potential synergies between these two types of education in approaching the plastic waste issue. Being global and transboundary by nature, the pollution challenge requires an equally transdisciplinary and transboundary approach, constant exposure to and exchange of global best practices, and an increased ability to collaborate for the joint solution of this ubiquitous issue. A further advantage of non-formal educational approaches to teach about the plastic waste issue is that all of the initiatives we have seen are completely open access and free for participants. There are no entry requirements which means that wider audiences of all ages, income, and background groups are included in the educational process on an issue of such a major environmental and societal importance. From this viewpoint, formal education could borrow interactivity and abundance of perspectives that characterize non-formal educational initiatives we have seen.

4.3 Sustainability Games

In the section on Formal Education, we already referred to several games developed for primary and secondary school students.

Sustainability games, or environmental games, are an excellent educational tool and a format that has been gaining popularity in sustainability education and that has proved to be extremely efficient in that task. It is beyond the scope of this work to analyze the history of such games and how they were first introduced to teach sustainability, as this would require a substantial amount of detail. For the purposes of this overview, we would like to mention environmental games as an efficient non-formal educational tool to teach sustainability in a non-formal and interactive way.

The MARLISCO project, which was mentioned in the previous section, supplemented their suite of marine-litter-related activities with a *Serious Game* translated into 15 languages. This way of learning through dilemmas and choices that players make is a good supplementary educational tool for learners of any age.

The Center for Systems Solutions in Poland specifically focuses on developing and applying groundbreaking methods and tools to collaboratively develop creative and inclusive solutions for urgent global challenges, such as climate change, shrinking resources, or growing inequalities. The unique tool they have developed that allows participants with diverse backgrounds and values to interact with each other in a shared environment, reflecting the key aspects of the real world, is social simulations. Social simulations "provide an accessible problem representation and engage stakeholders into dialogue," helping them find robust and sustainable solutions [43]. During a simulation, players have an opportunity to face real problems, try themselves in new roles, confront opposing views, and solve conflicts via negotiations and dialogue. As a result, these simulations enable participants to expand and revise their worldviews. They also help display misconceptions and demonstrate interconnections, the understanding of which is so critical to sustainability, and can be not obvious from a purely theoretical classroom learning.

Currently available social simulations developed by the Center do not specifically include plastic pollution. The games developed until now deal with pollution in general. However, the game mechanism is such that even without a specific focus on plastic, these games demonstrate the immediate connection between pollution, human, and environmental well-being and the interconnection between economic growth, consumption, and pollution. These interconnections, experienced firsthand during a simulation, serve the purpose of educating the public of the sources and impacts of pollution, and during a detailed debriefing that follows every game, session plastic pollution patterns can be pointed out.

The two social simulations that include pollution are Nexus Game and World's Future. Nexus Game takes the player through a process in which pollution of the

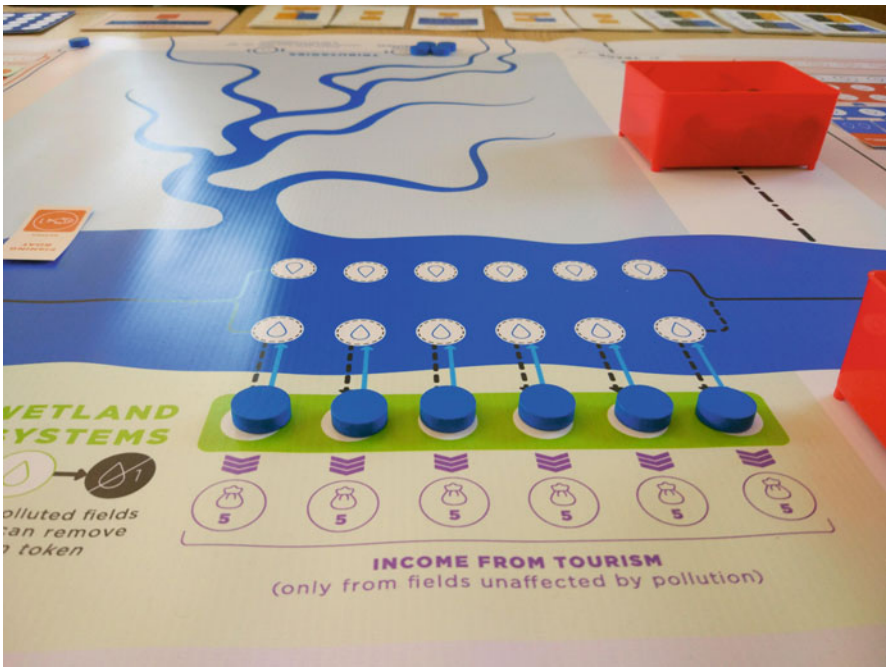

Fig. 5 Nexus Game by Center for Systems Solutions, Poland. Photo credit: Olga Mironenko

river blocks their own income from tourism and, if accumulated beyond the ecosystem's self-cleaning capacity, kills the entire ecosystem [44] (Fig. 5). The latter impacts agricultural activities in the area and brings about a range of repercussions for the player.

The World's Future is a social simulation in which players adopt high-level leadership roles and, as the simulation progresses, experience the pressure of making tradeoffs and the joy of finding synergies involved in pursuing sustainable development of their country [45]. The game shows the interdependencies of the global Sustainable Development Goals and makes a strong point that no sustainability is achievable without a healthy clean environment. As the pollution accumulates, it poisons the groundwaters and ends up in the ocean, affecting the fish reproduction rates. At a certain level of pollution, the health of the city population will also go down, triggering a whole range of social and economic issues. The game thus delivers a powerful message of the dangers of pollution, and the more recklessly the player is playing, the sooner this message becomes obvious. At the same time, the game provides a number of instruments to minimize and prevent pollution, such as investing in recycling facilities, choosing green products and services, etc.

In the near future, the Center for Systems Solutions is planning to start working on a social simulation on ocean sustainability and governance, which will

specifically include plastic pollution, its sources, and interconnections with current production and consumption patterns.

4.4 Mobile Exhibitions

The last non-formal educational format that we would like to bring forward as a popular and effective way to raise awareness of plastic pollution is mobile exhibitions.

These events are open to a large and very diverse range of audiences and usually take place in easily accessible locations so that they can be visited by substantial amounts of people. Therefore, a mobile exhibition is a perfect entertaining way to deliver an educational message to the public and create a momentum in the countries that the exhibition travels to.

It seems especially advantageous to engage individuals who would not consider enrolling in any sustainability educational programs, even non-formal ones, or cannot allocate sufficient time for that. An exhibition can be an efficient and quick way to give nuggets of knowledge on environmental issues. The format of an exhibition, as opposed to a scientific publication, or the overwhelming majority of courses, given the visuality of its exhibits, allows to incorporate art and deliver an important sustainability message in a creative and inspiring way. If this is done successfully, the message will stimulate the visitor to do independent research and find out more on the topic. Thus, an exhibition is a good way to engage the audiences that may not be motivated or knowledgeable enough on the issue to search for more information. In this regard, they could be considered a useful complementary educational tool to apply in science communication with the general public.

The two examples of mobile exhibitions on the plastic pollution problem are the MARLISCO Mobile Awareness Exhibition and the Ocean Plastics Lab.

The Mobile Awareness Exhibition is an awareness raising exhibition on the topic of marine litter within the MARLISCO project, aiming to inform the general public and the educational community of the issue [46]. It travelled to MARLISCO partner countries to such locations as museums, aquariums, and research centers and was also utilized for educational purposes during school visits, beach cleanups, etc. [47].

During the lifetime of MARLISCO, the displays in the 14 countries in which the exhibition took place reached 100,000 people. Interestingly, the exhibition was translated and mounted in Norway already after the project ended, which speaks to the high demand for such educational content.

Ocean Plastics Lab is an international travelling exhibition showcasing the contribution of science to understand and tackle the problem of marine plastic pollution and educating the public on the issue [48]. Ocean Plastics Lab was initiated by the German Federal Ministry of Education and Research together with the German Marine Research Consortium. The exhibition, which has already travelled to six countries, is designed as a hands-on science lab, inviting visitors to explore the extent and impact of plastics in the ocean over the course of the four containers.

5 Summary and Conclusions

We have reviewed the approaches that both formal and non-formal education institutes and initiatives are currently offering to raise awareness of the plastic pollution issue and enable their audiences to tackle it.

We have seen the diversity of primary and secondary school educational programs on the waste issue around the world. The existing projects are initiated by a whole range of stakeholders of all levels: individual researchers, nonprofit organizations, start-ups, and governmental bodies. These projects can be an entire curriculum or a stand-alone class on plastic waste and its impacts. It can be a game or a day on the beach sampling sand for microplastics and analyzing results. However, the overwhelming majority of the diverse projects we analyzed are external expertise that schools can resort to, in order to enrich the formal curriculum with the real-world environmental issues. Only a couple of projects we selected for this overview developed the expertise within the schools and made sure that theory went hand in hand with practice. These projects also facilitate recycling infrastructure in schools and thus enable students to apply the knowledge they obtain in plastic-related classes.

It is important, though, that setting up recycling infrastructure in schools or including training in sustainability topics into every teacher's qualification requirements is the domain and responsibility of the Ministries of Education and cannot be expected from grassroots initiatives. In this light, we would like to highlight the effort of Green Indonesia, which introduced school waste banks on several islands in Indonesia, along with the educational activities relevant to the issue of plastic.

Looking back on the actions suggested in *A Strategy for Sustainable Living*, we also see that sustainability has not become part of other school subjects, as was the plan in 1991, and we are moving at a slower pace than expected.

In this overview we have also seen the initiatives taken by universities, some of which are also incorporating the topic of plastic pollution into both their research and teaching, but as with schools, waste education has not become an inherent part of tertiary-level courses unrelated to the environment. We found only few examples of this practice.

These gaps in both school and university education result in yearly cohorts of graduates mostly unprepared for the crisis they will face right outside their classroom walls and reveal that the global formal educational system has not picked up the urgency of the plastic waste crisis yet.

This brings us onto a very important gap we have found in the course of preparing this overview – lack of stakeholder collaboration, particularly concerning collaboration with the governments and a consolidated vision of a strategy to tackle the plastic problem on all levels of the global educational community. What we currently see is a wide range of mostly uncoordinated educational initiatives from a variety of stakeholders. Unfortunately, despite the scale of the plastic crisis, these initiatives have neither become part of the educational system nor, for the most part, received any substantial support from the governments. Quite to the contrary, only a

small portion of the projects we have mentioned enjoys governmental support while dealing with an issue of critical societal and environmental importance. The majority of the projects listed here have no support from their governments and are struggling for funding and other resources. For this reason, we cannot stress enough how critical it is for governments to incorporate sustainability education across the entire formal educational system and, until this has been done, support and collaborate with local waste education initiatives.

We have also analyzed non-formal educational initiatives and programs that currently exist and have seen how these can cover wider audiences and use a whole suite of formats to deliver the sustainability message. This can be sustainability games – an excellent interactive educational tool for all ages and backgrounds; travelling exhibitions, which prove efficient in getting the message across to the general public; MOOCs; and other online training opportunities, many of which also include the plastic challenge into their content as an environmental issue of utmost importance.

Given this diversity of efforts, there is one gap that we see in non-formal education practices. This gap is the need to target waste education. To illustrate this point, there are a multitude of initiatives and courses for the general public, but it is the fishermen and the entire fishing industry who need to be taught sustainable fishing practices, including the use of sustainable fish aggregating devices (FADs), the proper use and recovery of fishing gear, and other nuance of using plastic gear. Similar targeted high-quality education on the impacts of plastic pollution must reach event and packaging industries, commerce and public catering, etc. All of these stakeholders contribute significantly to the global plastic waste generation. Hence, there is already a pressing need for a targeted sustainability education, which would include best practices for each industry known to contribute waste to plastic pollution.

Finally, something that both formal and non-formal education also have to address to successfully overcome the current plastic pollution crisis are our mental models underlying our choices and decisions. When we consider our unsustainable production and consumption patterns, it is our mental models that lead to the extensive and most often totally unnecessary use of disposable plastics, which end up in the environment. Behind practically every disposable plastic item we use, there is a certain mental model, carefully shaped by the advertising and manufacturing industries. An example of this would be disposable take-away cups, which have been heavily advertised worldwide as an attribute of a successful life and accomplishment. It does not take science to dispel the delusion, but it does take education to do so. Education at all levels should contribute to debunking these myths and correcting the faulty mental models, and this can be done by explaining what plastics really imply for the entire biosphere and what the sustainable alternatives are.

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Stakeholder Analysis in Solving the Problem of Accumulation of Plastics in Surface Waters of Protected Areas

Vesna Kicošev and Laszlo Galambos

Contents

Abstract Although various social networks and several research articles published have increasingly been pointing to the detrimental effects of plastics on the living organisms, the collective awareness of this problem is at a relatively low level. The accumulation of plastics in surface waters is one of the problems that affect the functionality of the ecosystems and reduce their resistance to various negative impacts. The consequences of changes in ecosystems significantly have impact on the economic effects of activities that depend on ecosystem services, including touristic activities. Since the preserved environment encourages a greater willingness to pay higher prices for services, ecotourism is one of the main instruments for promoting the economic value of protected areas. Sustainable forms of tourism include strategies for the management of protected areas both with measures for prevention and in a way to reduce the negative impacts on the environment. In order to effectively implement these measures, it is necessary to raise the ecological awareness of the visitors and the local population about the consequences that the accumulation of plastics in surface waters have on the living organisms and on the quality of ecosystem services.

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Through stakeholder analysis, which is a social research method suitable for making decisions on the conservation of natural values, a research of social factors was carried out, as well as the raising of ecological awareness. A thematic education program was developed for the purpose of stakeholder analysis; the attitudes of stakeholders were assessed by conducting interviews. The development of the education program and interviews focused on the impact of plastic accumulation on the deterioration of the quality of certain ecosystem services. The pilot research localities included wet and aquatic habitats within protected areas along the riparian zones and floodplains of the Danube River in Serbia.

Keywords Danube River, Ecosystem services, Plastics, Protected areas, Serbia

1 Introduction

The imposed excessive use of resources results in the creation of large amounts of waste, where plastics have a significant share. Being artificial materials, plastics have a negative connotation, even more so when found in natural environments [1]. Due to the durability, plastics can persist in the environment up to several 100 years [2]. Coupled with other anthropogenic influences, the accumulation of plastics affects the deterioration of ecosystem functions. Focus on the pollution with plastics has significantly increased over the last decades, especially since the turn of the millennium [3]. In many cases, there are aesthetic reasons for this, which have political, social, and economic consequences, e.g., when there is a risk of losing tourism revenues [4–7].

Plastics reach the soil and the aquatic environment as small particles or in the form of large pieces which later decompose into the so-called secondary microplastics. Secondary microplastics are considered to be the main source of microplastic pollution [8]. A significant source of microplastics is the plastic waste that reaches the environment. Thus the implementation of the regulations on sustainable waste management has particular importance. In the Republic of Serbia, under the provisions of the Law on Packaging and Packaging Waste ("Official Gazette of the Republic of Serbia" No. 36/2009), the Environmental Protection Agency prepares annual reports on the management of packaging and packaging waste. The latest available report was published in 2018 and provides a comparative overview of the data for the 2014–2017 period. Based on the analysis of data on collected and reused plastic by operators of the packaging waste management system, the quantity of the reused plastics in this period approximately tripled from 13,641 tons to 35,856 tons. However, the part of the total amount of plastic waste that is being recycled is still extremely small.

Over the past year, during commercial breaks on national broadcasting channels, videos and images of plastic waste accumulations were shown along with the appeal to reduce the use of plastic bags. Starting in 2017, the Ministry of Environmental Protection has come to an agreement with sales networks (supermarkets,

hypermarkets, convenience stores) that plastic bags in their stores will be charged. In the interview given on 16 July 2018 to the national broadcasting channel of the Republic of Serbia (RTS – Radio Televizija Srbije), Goran Trivan, the Minister of Environmental Protection, stated: "From the first day when the price of 2 dinars per plastic bag was introduced, the effect was immediate, as the consumption of bags and their usage was reduced by 50%. The effectiveness of this measure has improved as we speak, since the implementation of payments for plastic bags and their use has reduced by 60%" [9]. Similar measures had positive effects in other countries as well. In the United Kingdom in 2015, the introduction of a fee of 5 pence per plastic bag instead of a ban resulted in a reduction of their consumption by 85% [10]. Prevention is also much more cost-effective and environmentally friendly compared to post-consumer cleanup schemes [10], many of which are economically or technologically unfeasible.

The economic system developed for sustainable resource management reviews the issue of expenditure and social issues in the environment, both in monetary units and other indicators (e.g., nonmarket assessment methods) [11]. Direct nonmarket methods are based on the estimation of the readiness to pay for the protection of the environment in a hypothetical market scenario. Ecosystem approach in making economic decisions is a strategy related to the integrated management of the environmental components, which promotes preservation and sustainable use of natural values.

Within the scope of the United Nations global project "Millennium Ecosystem Assessment" [12], the ecosystem approach identifies four categories of services: supporting services (e.g., soil formation and complex processes of nutrient cycles), reservation services (the possibility of obtaining food, water, materials), regulation services (regulation of the climate, hydrological processes, erosion and natural disasters, water purification, and waste treatment), and cultural services (spiritual and aesthetic experience, recreation, possibilities of formal and informal education). The ecosystem services of natural ecosystems are under growing anthropogenic pressure. The newly developed concept of payments for ecosystem services helps the improvement of ecosystem services. Payments for ecosystem services are being primarily implemented by users of natural resources. So far, the application of this concept was non-binding.

The research topic of the pilot project is stakeholders' attitudes about the deterioration of the quality of cultural ecosystem services in some protected areas in Vojvodina Province (Fig. 1), Republic of Serbia, caused by the accumulation of plastic waste in surface water, which has a negative impact on tourism and recreation. Aquatic habitats and wetlands on protected areas located in the riparian area of the Danube River were selected as the research localities as the Danube River represents an ecological corridor of international importance (Bylaw of ecological network ("Official Gazette of the Republic of Serbia" No. 102/2010)).

Aquatic and wet habitats provide a number of vital ecosystem services inside their catchment basin as well as within a much larger area. These services include food and water procurement, regulation of microclimate, flood retention, cultural services of recreation, and aesthetic pleasure, as well as providing assistance in nutrient cycle.

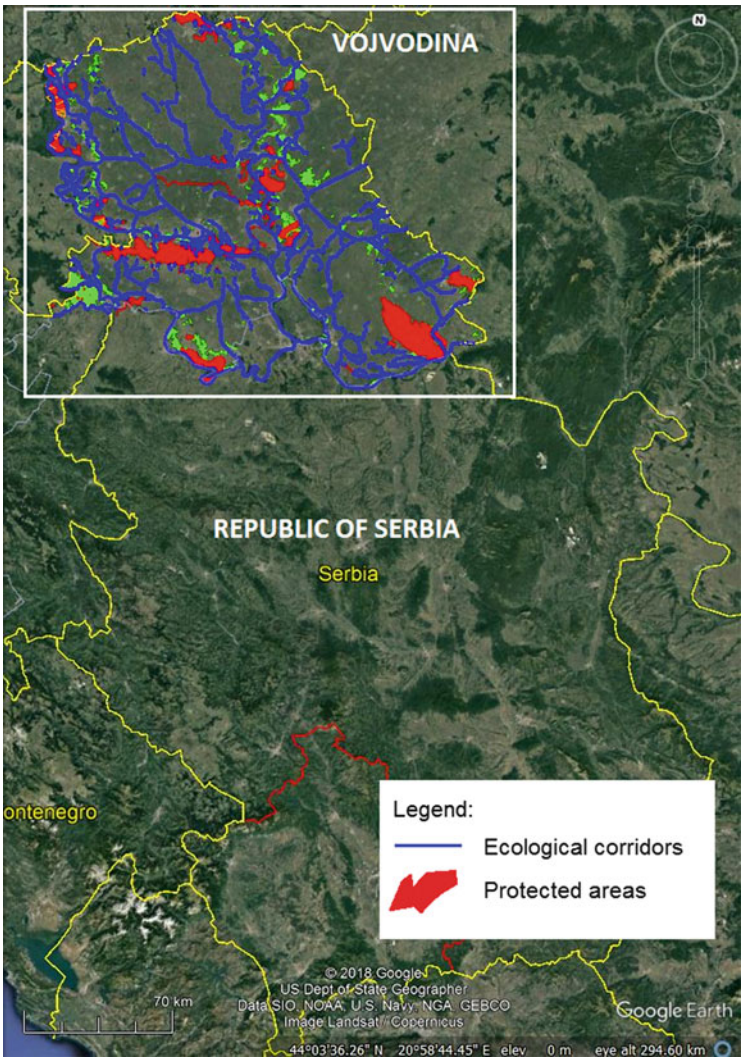

Fig. 1 Protected areas and ecological corridors in Vojvodina Province Kicošev, V. Source: Google Earth Pro. Google Maps (2018)

Swamp and pond ecosystems are able to eliminate toxic substances, heavy metals, as well as surplus of organic matter from water and sediments [13, 14]. They are especially rich in macrophytes and microorganisms which take part in denitrification and other biochemical processes which improve the quality of water. These organisms are very reliable in the elimination of suspended particles, phosphorous and nitrogen compounds, and are used as an integral part of water treatment [15]. The

ecosystem services of floodplains have the highest economic value (around $20,000 annually) compared to all of the ecosystems in the temperate zone [16].

2 Materials and Methods

The protected areas in the riparian area of the Danube River were selected based on the existing data on habitats which are endangered by the accumulation of plastics in the water and along the riparian area. The protected areas "Deliblatska peščara" Special Nature Reserve (Decree on the protection of "Deliblatska peščara" Special Nature Reserve ("Official Gazette of the Republic of Serbia" No. 3/2002 and 81/2008)), "Koviljsko-petrovaradinski rit" Special Nature Reserve (Decree on the protection of "Koviljsko-petrovaradinski rit" Special Nature Reserve ("Official Gazette of the Republic of Serbia" No. 44/2011)), and "Tikvara" Nature Park (Decree on the protection of "Tikvara" Nature Park ("Official Gazette of the Municipality of Bačka Palanka", No. 4/2015)) were selected according to the degree of vulnerability of the selected localities. The overview of the surveyed areas is shown on Fig. 2.

The data on the borders of the protected areas was acquired from the electronic database of the Institute for Nature Conservation of Vojvodina Province. The borders of the PAs were established by digitizing cadastral maps in scale 1:2,500 in ESRI ArcGIS 10 software. The research localities were digitalized using the

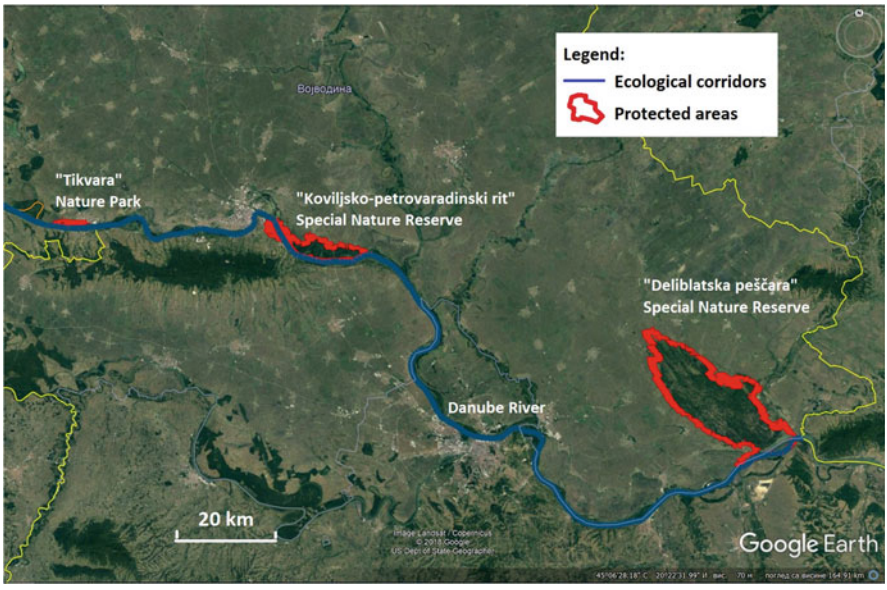

Fig. 2 Selected protected areas in the riparian area of the Danube River Kicošev, V. Source: Google Earth Pro. Google Maps (2018)

available ortho-photo imagery and high-resolution satellite images from Google Earth Pro. The graphical presentation of protected areas was obtained by transferring geographic data from GIS application onto a layer of satellite image (Google Maps) by reprojection and conversion.

The field research included both visiting of the selected habitats and surveying the visitors:

1. Field visit of the habitats was conducted on selected protected areas, where plastic accumulation was noted.
2. The *stakeholder* survey covered (a) 120 visitors of the protected area and (b) 231 residents categorized into respondent groups based on monthly incomes.

This research was carried out in parallel with the activities on expert supervision of protected areas, conducted by the Institute for Nature Conservation of Vojvodina Province in accordance with the annual work program. Due to time and financial constraints, the assessment of habitats was carried out based on existing data on the spatial distribution of habitats which are endangered by the accumulation of plastics. The *visitor* survey was planned based on the information about the confirmed organized tourist visits acquired form the managers of the protected areas. Taking into account the aforementioned facts, it was possible to conduct the research during 4 days in the period between 6th and 22nd August 2018. The accessibility of the endangered habitats allowed the assessment to be carried out by hiking along the riverbank. In accordance with the research objective, during habitats assessment, detailed analysis of the endangered habitats has not been conducted, and then insight into the selected habitats was made regarding the current situation with plastics on them (which was documented with photographs). The accumulated plastics were recorded on the locality "Stevanove ravnice" inside "Deliblatska peščara" Special Nature Reserve (Fig. 3) and near the town of Sremski Karlovci in "Koviljsko-petrovaradinski rit" Special Nature Reserve (Fig. 4). Prior to the field survey in "Tikvara" Nature Park, the accumulated waste was removed. Besides the accumulated plastics on the selected localities, scattered plastic waste was also visible on the

Fig. 3 Plastics inside "Deliblatska peščara" SNR, the locality "Stevanove ravnice." Photo by Kicošev, V.

Fig. 4 Plastics inside "Koviljsko-petrovaradinski rit" SNR, the locality near the town of Sremski Karlovci. Photo by Kicošev, V.

protected areas, which causes further damage to the image of the protected area. Photographs from the field were used in the development of the education program, which was presented in the section of the stakeholder analysis that was carried out after the field research.

The stakeholder analysis is the most effective social research method for decision-making in nature protection. For the past few decades, the stakeholder analysis has been a significant part of the nature protection practice in the international framework (the International Union for Conservation of Nature IUCN, World Wildlife Fund, etc.). After the adoption of the Law on Nature Protection ("Official Gazette of the Republic of Serbia," No. 36/2009, 88/2010, 91/2010) within the conservation studies which are a scientific and professional basis for the proposal of the act on declaration of the protected area, the analysis of stakeholders became the basis for determining the perspective for the sustainable development on the territory of the Republic of Serbia [17].

The involvement of local citizens in the management of natural resources has certainly broaden the overall scope of environmental management, integrating the biological, cultural, and social dimensions, and has led to greater responsibility within the local community in terms of nature conservation [3].

Stakeholder analysis was carried out mostly during the period of field research. The survey of stakeholders' attitudes was conducted by direct conversation and interviewing by filling out the questionnaire. Part of stakeholder analysis was carried out following the field research, with the presentation of an education program that was formed on the basis of field research and literary sources. The survey contains seven questions (Fig. 5), and most of the answers are completed by selecting the offered options. Since this is a pilot project, for the consideration of socioeconomic aspects of the problem, several important groups of stakeholders were selected. The results of the analysis of the collected responses may represent guidelines for further, more detailed research.

The survey which was conducted on protected areas covered both domestic and international tourists. The comparison of their answers can indicate whether, and to

QUESTIONNAIRE

1. Choose three of the listed services (benefits) provided by nature that are significant to you.

A) fishing B) swimming C) riding a boat D) recreation on the ground E) observing and / or photographing F) spiritual experience G) learning through practice

2. Select three sources of pollution that have the most negative impact on nature.

A) communal sewage B) pollution from arable land C) infectious waste (illegal dump sites for dead cattle) D) plastics E) fuel and oil F) air pollution by exhaust gases

3. Do you think there is a problem of accumulating plastics in water and coastal areas?

A) No B) Yes, but to a lesser extent C) Yes, there is a significant problem

4. Have you heard about the problem of the existence of microplastics (tiny plastic parts) in water (if so, what is the source of your knowledge)?

A) No B) Yes _____

5. Have you heard about the harmful effect of plastics on the living world (if so, what is the source of your knowledge)?

A) No B) Yes _____

6. Do you find important the knowledge about the quality of services provided by nature (for example, water quality) in the process of selecting the area where you are staying?

A) No B) Yes

7. Would you be willing to pay (if yes, how much) for all-day stay in an unpolluted natural environment?

A) No
B) Yes: 1) 5–10 € 2) 10–20 € 3) 20–50 € 4) over 50 €

On the back of the Questionnaire you can write your opinion and suggestions regarding any of the questions above.

THANK YOU FOR YOUR COOPERATION!

Fig. 5 The questionnaire for the stakeholder analysis Kicošev, V.

which extent, the different social environment influences the available information on the problem of accumulation of plastics and whether it leads to the formation of different attitudes about the importance of each individual's participation in the preservation of the natural environment. Among foreign 45 visitors, there were

tourists from Bosnia and Herzegovina, Bulgaria, China, Croatia, Germany, Macedonia, and Slovenia.

During the field research, the survey sheets were also filled in by the local population with different incomes. Taking into account the fact that the average salary in Serbia in August 2018 was about 430 Euros (Statistical Office of the Republic of Serbia 2018), a rounded amount of 500 Euros was selected as the limit value between the groups in order to simplify the analysis of the results. One of the goals of comparing the responses of these groups of respondents is to determine whether and how the amount of monthly income can affect the willingness of individuals to financially contribute to the preservation of the natural environment.

The stakeholder analysis which was carried out after the field research started from the assumption that the stakeholders will be more open to cooperation on the preservation of natural resources if they are better informed. Therefore, this analysis was conducted in two ways:

1. Electronic questionnaires were sent out by e-mail to selected groups of respondents who have the possibility to get informed about the issue of the water pollution by macro- and microplastics through their everyday work. Among them are the employees of the communal and water management companies. Journalists were selected as a separate group for surveying by sending them electronic questionnaires. Out of the 150 questionnaires we sent out, 102 were filled out and returned.
2. The education program was presented to the survey participants of various professions (that are not related to the topic of microplastics). After the completion of the program, the questionnaires were handed out to the participants. The topic of the education program for the stakeholder analysis was "How do we protect our waters?". The interview was used as the method for examining the stakeholders' attitudes. The development of the education program and the survey focuses on the impact of accumulation of plastics on the deterioration of the quality of ecosystem services provided by the nature. The impact of the accumulation of plastics in surface waters on the deterioration of cultural ecosystem services was emphasized. These services include recreation, spiritual and aesthetic experiences, and possibilities of formal and informal education. The education program was presented at the Institute for Nature Conservation of Vojvodina Province (Fig. 6). All 66 participants on the presentations of the education program filled out the questionnaires. In the scope of the education program, stakeholders got familiar with the importance of preserving natural habitats. It was highlighted that the state of the riverbanks and the riparian areas is of key importance for the development of different forms of tourism and recreation. The issue of plastic accumulation in the water was presented through the results of the field research on the localities within the protected areas. The negative effects of plastics on the wildlife were presented based on the experiences acquired during the Summer School "Plastics in Marine and Freshwater Environments" (German Federal Institute of Hydrology, Koblenz, 16–21 July 2017). The conclusions and

Fig. 6 Presentation of the education program and the stakeholder analysis Photo-documentation of Institute for Nature Conservation of Vojvodina Province

recommendations from the Summer School as well as the results of the research published in numerous scientific papers helped to demonstrate the possible ways of managing plastics in the future.

Since the research topic of the pilot project is the analysis stakeholders' attitudes about the deterioration of the quality of cultural ecosystem services in protected areas, the questionnaire (Fig. 5) was formulated as follows:

1. Valuation of the importance of selected ecosystem services: fishing, swimming, riding a boat, recreation on the ground, observing and/or photographing, spiritual experience, and learning through practice about natural values (Question no. 1).
2. Estimation of threats (one of them is plastic accumulation in the water and riparian areas) to natural values which are the basis for providing ecosystem services (Question no. 2 and Question no. 3).
3. Analysis of the awareness of the survey participants about the problem of microplastics in the water and the impact of plastics on wildlife (Question no. 4 and Question no. 5).
4. Analysis of the attitudes of participants toward the importance of the preservation of the quality of ecosystem services (Question no. 6).
5. Valuation of the importance of unpolluted natural environment by the willingness of the survey participants to pay for ecosystem services (Question no. 7).

3 Results and Discussion

The survey results are based on the analysis of the responses given in the questionnaires by groups of participants. The groups were formulated based on the possible means of use of ecosystem services and the intensity of their impacts on protected areas: (1) domestic and foreign visitors, (2) respondent groups based on monthly incomes, (3) employees of the communal and water management companies, (4) journalists, and (5) respondents who attended the education program.

3.1 Presentation of the Views of Stakeholders per Respondent Groups

3.1.1 Domestic and Foreign Visitors

The assessed aquatic and wet habitats in the riparian areas of "Deliblatska peščara" Special Nature Reserve, "Koviljsko-petrovaradinski rit" Special Nature Reserve i "Tikvara" Nature Park, provide a number of vital ecosystem services, primarily due to rich biodiversity. Even though these areas cover only a small percent of the protected areas (e.g., the locality "Stevanove ravnice" ($P = 108$ ha) represents about 0.3% of "Deliblatska peščara" Special Nature Reserve ($P = 35{,}000$ ha)), due to their well-preserved natural values, they attract domestic and foreign visitors. Foreign visitors of protected areas in Vojvodina are mostly part of organized research or volunteer groups, cycling tours, etc. According to the survey results (Fig. 7), foreign visitors find most enjoyment in observing and photographing landscapes (29%). They prefer learning through practice about natural values in a slightly higher percentage (16%) compared to domestic visitors (13%).

Pollution caused by plastics was identified as the most significant threat to nature by domestic respondents (24%), while foreign respondents identified air pollution as the most significant threat to nature (24%). The pollution coming from arable land was ranked lowest by both respondent groups.

All domestic respondents (100%) identified the accumulation of plastics in the water as a significant problem, as well as most of foreign respondents (73%). The awareness of the harmful effects of plastics on wildlife were identified by all foreign respondents (100%), while in the group of domestic respondents, this percentage is 92%. In terms of awareness of the problem of plastics and microplastics, no significant difference was observed in the answers in the two groups.

Staying in a clean, unpolluted natural environment is important to 96% of domestic respondents. This percentage is less in the group of foreign visitors (60%), but at the same time, they are willing to pay for this service. Although not all domestic respondents who like the preserved natural environment have expressed willingness to pay for it, a slightly higher percentage (72%) is willing to pay for this service compared to the surveyed foreign visitors (60%). Regarding the estimation of

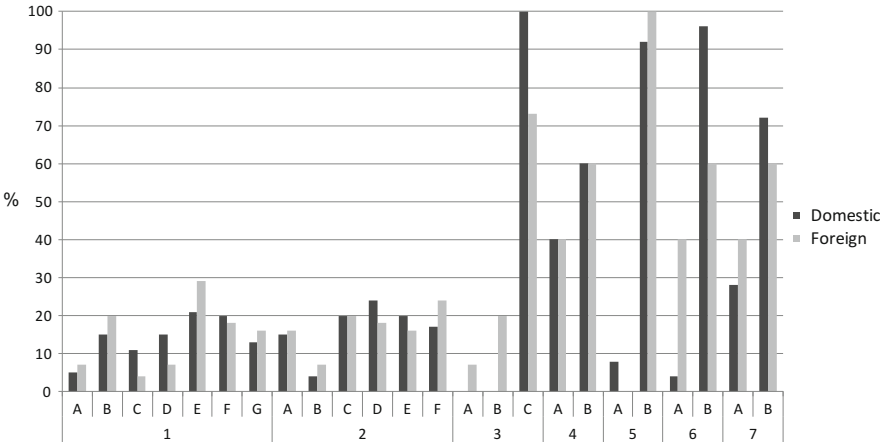

Fig. 7 Results of the questionnaire – domestic and foreign visitors. (1) Choose three of the listed services (benefits) provided by nature that are significant to you: (A) fishing, (B) swimming, (C) riding a boat, (D) recreation on the ground, (E) observing and/or photographing, (F) spiritual experience, (G) learning through practice. (2) Select three sources of pollution that have the most negative impact on nature: (A) communal sewage, (B) pollution from arable land, (C) infectious waste (illegal dump sites for dead cattle), (D) plastics, (E) fuel and oil, (F) air pollution by exhaust gases. (3) Do you think there is a problem of accumulating plastics in water and coastal areas? (A) No, (B) Yes, but to a lesser extent (C) Yes, there is a significant problem. (4) Have you heard about the problem of the existence of microplastics (tiny plastic parts) in water (if so, what is the source of your knowledge)? (A) No, (B) Yes. (5) Have you heard about the harmful effect of plastics on the living world (if so, what is the source of your knowledge)? (A) No, (B) Yes. (6) Do you find important the knowledge about the quality of services provided by nature (e.g., water quality) in the process of selecting the area where you are staying? (A) No, (B) Yes. (7) Would you be willing to pay (if yes, how much) for all-day stay in an unpolluted natural environment? (A) No, (B) Yes: (1) 5–10 €, (2) 10–20 €, (3) 20–50 €, (4) over 50 €

the value of the service (Fig. 8), twice as many foreign respondents chose lower value of prices (5–10 Euros and 10–20 Euros) compared to the group of domestic respondents, while significantly more than twice of the percentage of domestic (34%) compared to foreigners (12%) respondents decided for the value of 20–50 Euros. None of the foreign respondents considered that this service is worth more than 50 Euros, while a significant percentage of domestic respondents (22%) evaluated that this service costs over 50 Euros. Taking into account the fact that for most of the domestic visitors these protected areas are most commonly the sites for rest and recreation, it can be assumed that they value more the importance of preservation of natural habitats.

3.1.2 Respondent Groups Based on Monthly Incomes

Regardless of the officially published data, according to which the average salary in Serbia in August 2018 was about 430 Euros [18], the real incomes are about 15,000

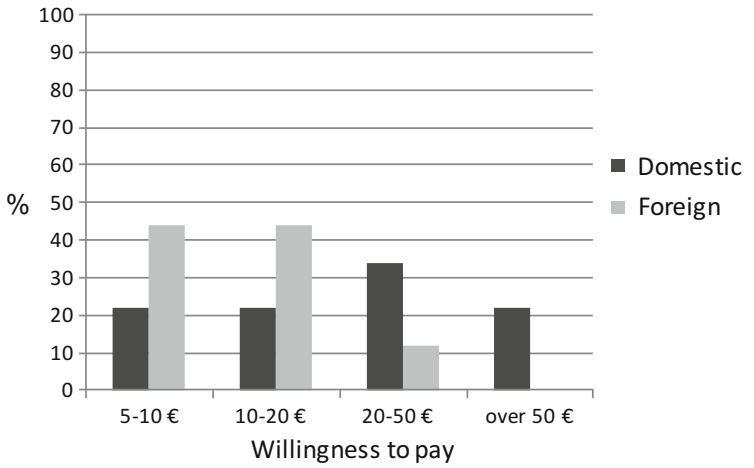

Fig. 8 Willingness to pay for ecosystem services – domestic and foreign visitors

RSD (127 Euros) less than the official average income [19]. The surveys made by Eurostat show that in 2018, approximately 62.8% of Serbian citizens couldn't afford having a vacation abroad [20], so protected areas more often become the choice for rest and recreation. According to the survey results (Fig. 9), the group of respondents with a salary less than 500 Euros prefers recreational activities related to aquatic surfaces of natural habitats such as fishing and boating, while those with a higher salary prefer walking and/or jogging along with observing and photographing the landscape.

By both groups of respondents, pollution with plastics was estimated as the most important threat to nature. Pollution originating from arable land was ranked the lowest. Approximately the same percentage in both groups of respondents (about 90%) considered the accumulation of plastics in water as a significant problem. A slightly greater percentage of respondents with a higher salary (98%) stated that they were already familiar with the harmful impact of plastics on the wildlife, compared to those with a lower salary (87%). From the group of respondents with a higher salary, 57% answered that they had the opportunity to hear about the problem of the existence of microplastics. In the group with lower salaries, 45% answered positively on this question.

For all respondents from the group with lower incomes, it is important to stay in a clean, unpolluted natural environment, and 81% of them are willing to pay for this service. A slightly greater percentage (83%) of respondents from the group with a higher income agree that they need to pay for staying in an unpolluted environment. In terms of estimating the value of the service (Fig. 10), the situation is quite opposite. A greater percentage of respondents with higher incomes chose lower prices (5–10 Euros and 10–20 Euros), an equal percentage from both groups decided for a value of 20–50 Euros, while twice as much percentage of respondents with a lower income estimated this service at a price above 50 Euros. Although in this case

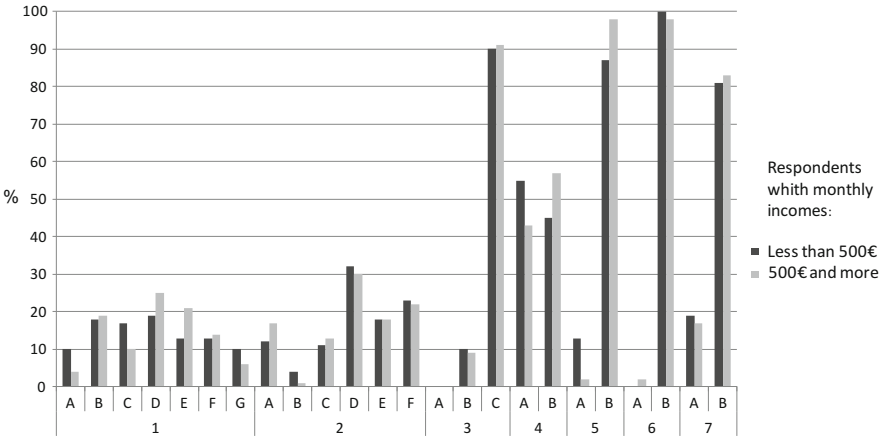

Fig. 9 Results of the questionnaire – respondent groups based on monthly incomes. Legend: (1) Choose three of the listed services (benefits) provided by nature that are significant to you: (A) fishing, (B) swimming, (C) riding a boat, (D) recreation on the ground, (E) observing and/or photographing, (F) spiritual experience, (G) learning through practice. (2) Select three sources of pollution that have the most negative impact on nature: (A) communal sewage, (B) pollution from arable land, (C) infectious waste (illegal dump sites for dead cattle), (D) plastics, (E) fuel and oil, (F) air pollution by exhaust gases. (3) Do you think there is a problem of accumulating plastics in water and coastal areas? (A) No, (B) Yes, but to a lesser extent, (C) Yes, there is a significant problem. (4) Have you heard about the problem of the existence of microplastics (tiny plastic parts) in water (if so, what is the source of your knowledge)? (A) No, (B) Yes. (5) Have you heard about the harmful effect of plastics on the living world (if so, what is the source of your knowledge)? (A) No, (B) Yes. (6) Do you find important the knowledge about the quality of services provided by nature (e.g., water quality) in the process of selecting the area where you are staying? (A) No, (B) Yes. (7) Would you be willing to pay (if yes, how much) for all-day stay in an unpolluted natural environment? (A) No, (B) Yes: (1) 5–10 €, (2) 10–20 €, (3) 20–50 €, (4) over 50 €

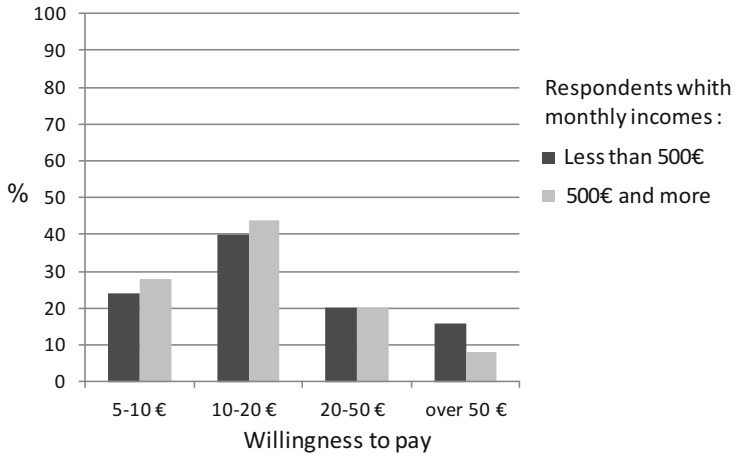

Fig. 10 Willingness to pay for ecosystem services – respondent groups based on monthly incomes

it may sound like an anecdote, but the survey results support the theory of many philosophers and theologians that the poor are more generous than the wealthy.

3.1.3 Employees of the Communal and Water Management Companies

The communication with employees of utility companies working on wastewater treatment revealed that the presence of microplastics in the water is a major problem for the operation of the treatment facilities. However, the operating companies do not possess technology for the removal of microplastics. Employees of the water management companies are often faced with the accumulation of plastic in surface waters during fieldwork, so their stance on the discussed topics has a significant importance.

According to the survey results (Fig. 11), pollution with plastics was identified as the most significant threat to nature. Pollution from arable land was ranked on the

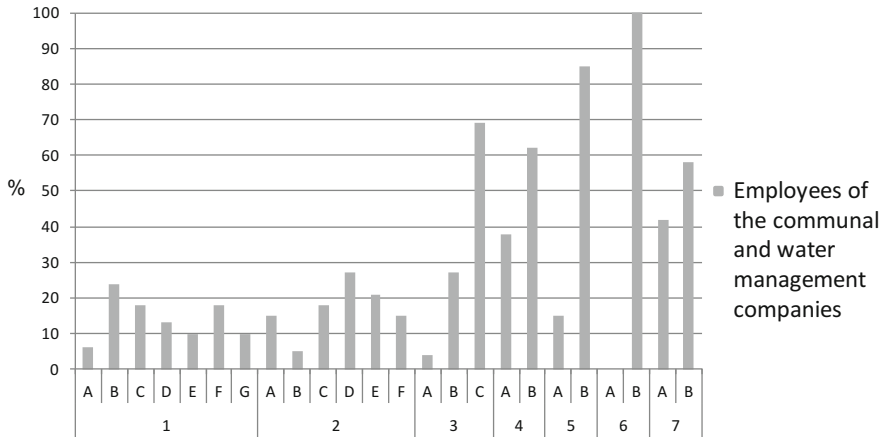

Fig. 11 Results of the questionnaire – employees of the communal and water management companies. Legend: (1) Choose three of the listed services (benefits) provided by nature that are significant to you: (A) fishing, (B) swimming, (C) riding a boat, (D) recreation on the ground, (E) observing and/or photographing, (F) spiritual experience, (G) learning through practice. (2) Select three sources of pollution that have the most negative impact on nature: (A) communal sewage, (B) pollution from arable land, (C) infectious waste (illegal dump sites for dead cattle), (D) plastics, (E) fuel and oil, (F) air pollution by exhaust gases. (3) Do you think there is a problem of accumulating plastics in water and coastal areas? (A) No, (B) Yes, but to a lesser extent, (C) Yes, there is a significant problem. (4) Have you heard about the problem of the existence of microplastics (tiny plastic parts) in water (if so, what is the source of your knowledge)? (A) No, (B) Yes. (5) Have you heard about the harmful effect of plastics on the living world (if so, what is the source of your knowledge)? (A) No, (B) Yes. (6) Do you find important the knowledge about the quality of services provided by nature (e.g., water quality) in the process of selecting the area where you are staying? (A) No, (B) Yes. (7) Would you be willing to pay (if yes, how much) for all-day stay in an unpolluted natural environment? (A) No, (B) Yes: (1) 5–10 €, (2) 10–20 €, (3) 20–50 €, (4) over 50 €

Fig. 12 Willingness to pay for ecosystem services – employees of the communal and water management companies

last place. Less than 70% of respondents consider that accumulation of plastics in the water is a significant problem, while 85% of them were already aware of the harmful effects of plastics on the wildlife. As many as 38% of respondents answered that they did not have the opportunity to hear about the problem of existence of microplastics in water. One of the conclusions may be that the respondents in this group (who need to be better acquainted with this topic) are less informed than the previous groups; however, we think that other respondents in the survey did not give completely honest answers.

For all respondents (100%) it is important to stay in a clean, unpolluted natural environment, but less than 60% of them are willing to pay for this service. When estimating the value of the services (Fig. 12), the largest number (53%) opted for the lowest price, but none of the respondents considered that this service is worth more than 50 Euros. This result of the survey is quite unexpected.

3.1.4 Journalists

Since the problem of plastic pollution is discussed more often in the media than in the period the past couple of years (primarily through the appeal to reduce the use of plastic bags), it is important to consider the attitude of the journalist regarding the research topic. According to the survey results (Fig. 13), pollution with plastics was identified as the most significant threat to nature. Pollution from arable land was once again ranked on the last place.

All respondents (100%) believe that the accumulation of plastic in the water is a significant problem, and all of them were already familiar with the harmful effects of plastic on the wildlife. The same percentage of respondents, as in the group of employees in communal and water management companies (38%), answered that they had no opportunity to hear about the problem of the existence of microplastics.

For all respondents (100%) in this group, it is important to stay in a clean, unpolluted natural environment, and they are all willing to pay for this service.

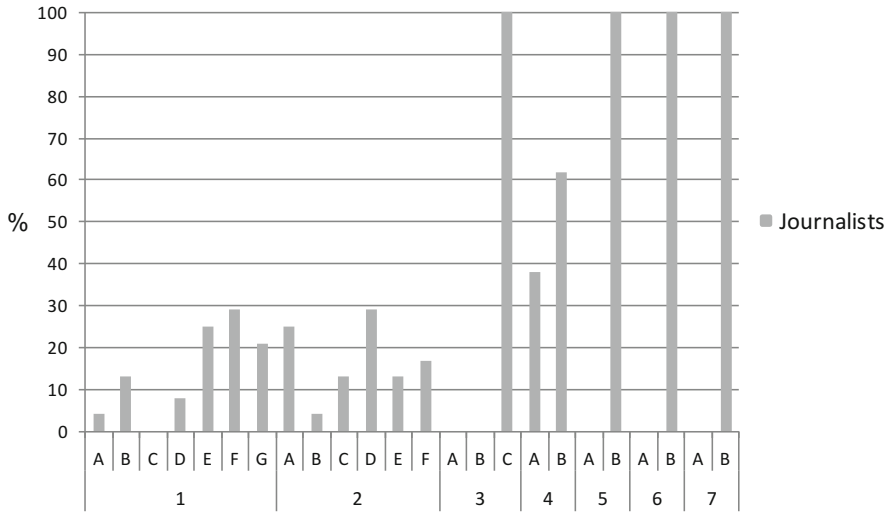

Fig. 13 Results of the questionnaire – journalists. Legend: (1) Choose three of the listed services (benefits) provided by nature that are significant to you: (A) fishing, (B) swimming, (C) riding a boat, (D) recreation on the ground, (E) observing and/or photographing, (F) spiritual experience, (G) learning through practice. (2) Select three sources of pollution that have the most negative impact on nature: (A) communal sewage, (B) pollution from arable land, (C) infectious waste (illegal dump sites for dead cattle) (D) plastics, (E) fuel and oil, (F) air pollution by exhaust gases. (3) Do you think there is a problem of accumulating plastics in water and coastal areas? (A) No, (B) Yes, but to a lesser extent (C) Yes, there is a significant problem. (4) Have you heard about the problem of the existence of microplastics (tiny plastic parts) in water (if so, what is the source of your knowledge)? (A) No, (B) Yes. (5) Have you heard about the harmful effect of plastics on the living world (if so, what is the source of your knowledge)? (A) No, (B) Yes. (6) Do you find important the knowledge about the quality of services provided by nature (e.g., water quality) in the process of selecting the area where you are staying? (A) No, (B) Yes. (7) Would you be willing to pay (if yes, how much) for all-day stay in an unpolluted natural environment? (A) No, (B) Yes: (1) 5–10 €, (2) 10–20 €, (3) 20–50 €, (4) over 50 €

Regarding the estimation of the value of the service (Fig. 14), the largest number (34%) decided for the value of 20–50 Euros, while 22% of respondents believe that this service is worth more than 50 Euros.

Another result of journalists' answering (53%), according to which Internet is ranked highest as the source of information collection (Fig. 15), supports the fact that research is increasingly being carried out through global networks. Less than half of the respondents reported the media as the source of information about the harmful effects of plastics on the wildlife.

3.1.5 Respondents Who Attended the Education Program

After the presentation of the education program, a discussion was held on the impact of microplastics on the wildlife and the possible effects of accumulation of plastics in

Fig. 14 Willingness to pay for ecosystem services – journalists

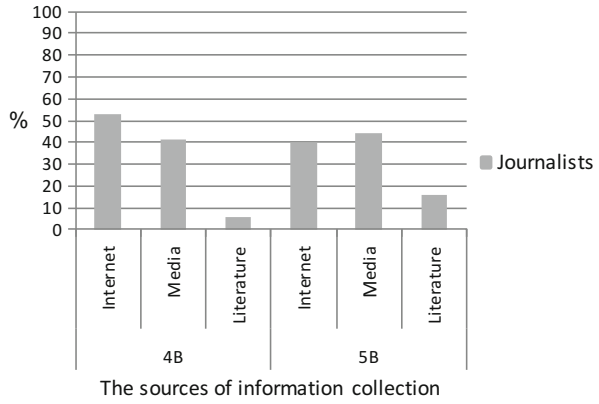

Fig. 15 The sources of information collection – journalists. Legend: (4B) Have you heard about the problem of the existence of microplastics (tiny plastic parts) in water (if so, what is the source of your knowledge)? (5B) Have you heard about the harmful effect of plastics on the living world (if so, what is the source of your knowledge)?

ecosystems. The participants were particularly interested about the information from the Summer School "Plastics in Marine and Freshwater Environments."

According to the survey results (Fig. 16), pollution with plastics was identified as the most significant threat to nature. Pollution from arable land was ranked lowest. The highest number of respondents (86%) believe that the accumulation of plastics in the water is a significant problem, and over 80% claim that they were familiar with the harmful effects of plastic on wildlife even before they attended the education program. A smaller percentage of respondents (45%) answered that they had no previous opportunities to hear about the problem of the existence of microplastics.

Although 95% of respondents consider it important to stay in a clean, unpolluted natural environment, 86% of them are willing to pay for this service. Of those who are willing to pay (Fig. 17), the highest number (53%) decided on the lowest price, and there were no respondents who considered that this service is worth more than 50 Euros. In conversations with the participants of the survey after the end of the education program, they declared their support to the implementation of preventive measures. Studies of stakeholder engagement that were conducted during the

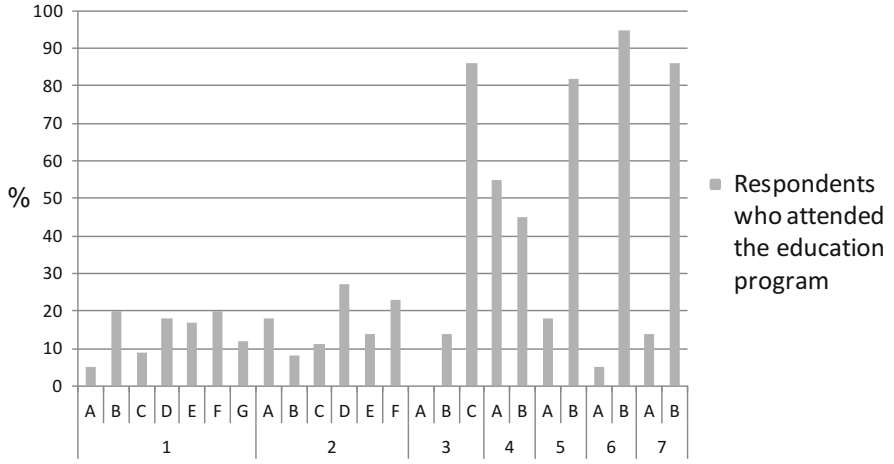

Fig. 16 Results of the questionnaire – respondents who attended the education program. Legend: (1) Choose three of the listed services (benefits) provided by nature that are significant to you: (A) fishing, (B) swimming, (C) riding a boat, (D) recreation on the ground, (E) observing and/or photographing, (F) spiritual experience, (G) learning through practice. (2) Select three sources of pollution that have the most negative impact on nature: (A) communal sewage, (B) pollution from arable land, (C) infectious waste (illegal dump sites for dead cattle), (D) plastics, (E) fuel and oil, (F) air pollution by exhaust gases. (3) Do you think there is a problem of accumulating plastics in water and coastal areas? (A) No, (B) Yes, but to a lesser extent, (C) Yes, there is a significant problem. (4) Have you heard about the problem of the existence of microplastics (tiny plastic parts) in water (if so, what is the source of your knowledge)? (A) No, (B) Yes. (5) Have you heard about the harmful effect of plastics on the living world (if so, what is the source of your knowledge)? (A) No, (B) Yes. (6) Do you find important the knowledge about the quality of services provided by nature (e.g., water quality) in the process of selecting the area where you are staying? (A) No, (B) Yes. (7) Would you be willing to pay (if yes, how much) for all-day stay in an unpolluted natural environment? (A) No, (B) Yes: (1) 5–10 €, (2) 10–20 €, (3) 20–50 €, (4) over 50 €

Fig. 17 Willingness to pay for ecosystem services – respondents who attended the education program

process of adoption of the Proposal for a Directive of the European Parliament and of the Council on the reduction of the impact of certain plastic products on the environment indicate that the global support for the implementation of preventive measures has been present globally. As stated in the Regulation of the European Commission [21], the implementation of measures for the ban on the use of disposable plastic cutlery along with the introduction of reusable alternatives have a high level of support (93%), even in case it would lead to a slight increase in prices.

3.2 Presentation of the Views of All Stakeholders

The results of the survey of the attitudes of individual groups of respondents provide an overview of the social aspect of this problem and can help in the formation of education programs for each stakeholder group. Due to the proven positive effects, this method is being applied in Vojvodina for many years for the purposes of education of stakeholders in different thematic units in the field of nature protection.

In order to obtain more realistic information about the opportunities by the society and nature protection policy in the fight against accumulation of plastics in surface waters, the analysis of the views of all respondents can provide significant assistance.

The results of the survey shown in Fig. 18 indicate that pollution with plastics is recognized as the most significant threat to nature. The pollution originating from arable land was ranked the lowest. This attitude of the respondents from individual groups is reflected as the dominant opinion of all respondents. From the professional point of view, the inflow of pollutants from arable land (as a diffuse source of pollution) is one of the biggest problems in nature protection.

The aggregation of smaller agricultural parcels into large ones for the purposes of production of monocultures (e.g., large areas under just maize or wheat), coupled with the inadequate use of chemicals in agricultural production (e.g., pesticides maluse), is causing increased soil erosion and higher levels of pollution. This leads to decrease in the number of wildlife species and biodiversity, loss of natural habitats, decrease in the quality of ecosystem services which provide water purification, and the spread of invasive species and other pests that are altering the natural processes in the ecosystems [22]. There are similarities between solving this problem and tackling the threats caused by the accumulation of plastics. Due to the inability to implement efficient construction, technical and technological protection measures, the progress of developing legislation in this area fell behind the regulations related to the reduction of emissions of pollutants from the construction areas. However, as noted above, the issue of plastics is recently becoming present in the public, so the knowledge about the risks associated with plastics are something new to the general public. Some researches [3] indicate that the risks associated with new technologies and new entities are generally considered to be more dangerous than risks that are older and already known, even if statistically the risks are approximately the same or even lower for the new risk.

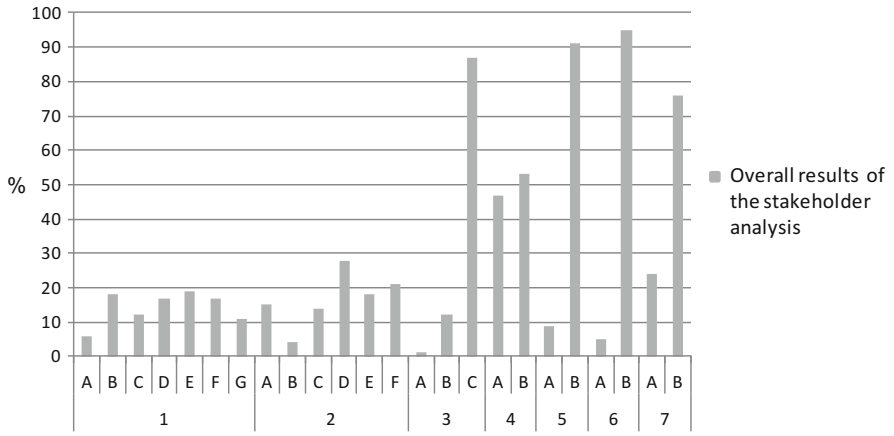

Fig. 18 Results of the questionnaire – overall results of the stakeholder analysis. Legend: (1) Choose three of the listed services (benefits) provided by nature that are significant to you: (A) fishing, (B) swimming, (C) riding a boat, (D) recreation on the ground, (E) observing and/or photographing, (F) spiritual experience, (G) learning through practice. (2) Select three sources of pollution that have the most negative impact on nature: (A) communal sewage, (B) pollution from arable land, (C) infectious waste (illegal dump sites for dead cattle), (D) plastics, (E) fuel and oil, (F) air pollution by exhaust gases. (3) Do you think there is a problem of accumulating plastics in water and coastal areas? (A) No, (B) Yes, but to a lesser extent (C) Yes, there is a significant problem. (4) Have you heard about the problem of the existence of microplastics (tiny plastic parts) in water (if so, what is the source of your knowledge)? (A) No, (B) Yes. (5) Have you heard about the harmful effect of plastics on the living world (if so, what is the source of your knowledge)? (A) No, (B) Yes. (6) Do you find important the knowledge about the quality of services provided by nature (e.g., water quality) in the process of selecting the area where you are staying? (A) No, (B) Yes. (7) Would you be willing to pay (if yes, how much) for all-day stay in an unpolluted natural environment? (A) No, (B) Yes: (1) 5–10 €, (2) 10–20 €, (3) 20–50 €, (4) over 50 €

The results of the survey of all respondents (Fig. 18) indicate that the largest number of respondents (87%) consider the accumulation of plastics in the surface water as a significant problem. Similar results were obtained during the stakeholder analysis in the process of the adoption of the Directive of the European Parliament and of the Council on the reduction of the impact of certain plastic products on the environment. The statements from Regulation (EC) No. 257/2018 indicate that the accumulation of plastics in the environment is considered to be a significant problem on an international level, according to the fact that a large number of respondents (84%) consider the cost of the cleanup of waste to be a very important or important issue. Although for 95% of respondents (Fig. 18) it is important to stay in a clean, unpolluted natural environment, only 76% are willing to pay for this service. Out of them (Fig. 19), the largest number (35%) opted for the lowest price, and only 10% of respondents from all stakeholders considered that this service is worth more than 50 Euros. By comparing the answers of different groups of respondents, we found that a different social status, social environment, and the amount of monthly income can affect the readiness of the individuals to financially contribute to the preservation of the natural environment, but sometimes in an unexpected way.

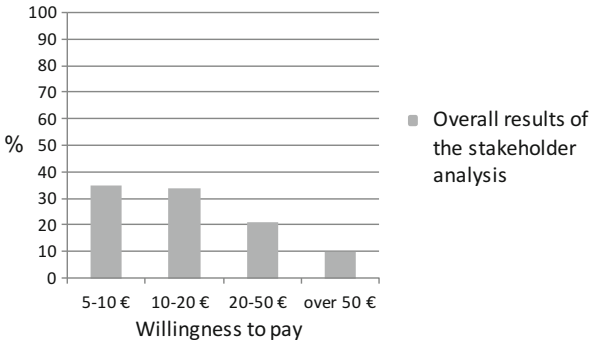

Fig. 19 Willingness to pay for ecosystem services – overall results of the stakeholder analysis

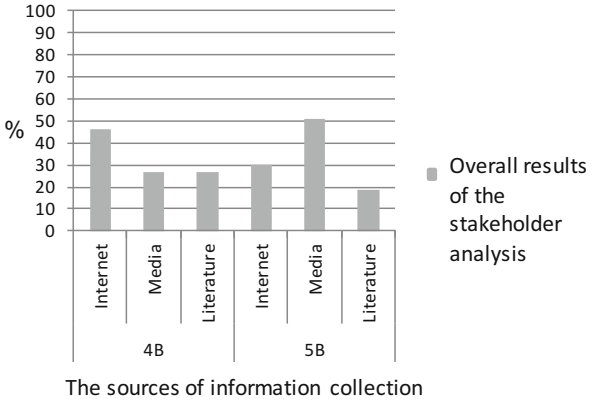

Fig. 20 The sources of information collection – overall results of the stakeholder analysis. Legend: (4B) Have you heard about the problem of the existence of microplastics (tiny plastic parts) in water (if so, what is the source of your knowledge)? (5B) Have you heard about the harmful effect of plastics on the living world (if so, what is the source of your knowledge)?

According to the survey results (Fig. 20), more than 90% of respondents claim to be familiar with the harmful effects of plastics on the wildlife, and more than half of them reported the media as a source for the information on this topic. A smaller percentage of respondents (47%) stated that they had no opportunity to hear about the problem of the existence of microplastics. The majority of the survey participants who claimed that they had the opportunity to get familiar with the microplastic issue (53%) stated that the Internet is the dominant source of information about microplastics (regardless of their age). This was one of the more surprising results of the survey, taking into account the fact that a significant part of professional public knows very little about the problem of microplastics in the environment. Additionally, the analysis of the data from the existing literature that was carried out for the development of the education program indicates that the publication of scientific papers on this subject is far more behind compared to most other topics in the fields of nature and environmental protection.

4 Conclusions

Although pollution with plastics is getting more in the focus of public attention, the importance of sustainable plastic management and prevention is not emphasized enough, even though it represents the most effective method for reducing the amount of plastic waste in the natural environment. Taking into account the role of stakeholders in the conservation of protected areas and management of water resources, the development of education programs for different interest groups is of particular importance.

The social status, social environment, and the amount of monthly income have a significant but not a decisive role in the readiness of the individual to contribute financially to the preservation of the natural environment in order to improve the quality of ecosystem services. The valuation of ecosystem services of natural habitats mostly depends on the level of the benefits that are provided as well as on the frequency of their use by stakeholders.

Since payments for ecosystem services are not an obligatory measure even on the international level, it is very important to integrate this concept in the national legislation and recognize it by different sectors. The valuation and payments for ecosystem services for different users of natural resources should be included in the regulations in the field of nature protection. A special fund should be opened for management of these finances, regardless of the existing fund for environmental protection. The removal of plastics from the surface waters and the cleaning of the environment, inter alia, should be financed from this new fund.

Acknowledgments Many thanks to the collaborators from the surroundings of the protected areas and to all respondents for their help in the analysis. Special thanks to the management of Institute for Nature Conservation of Vojvodina Province for enabling both the field research on the localities within the selected protected areas and the presentation of the education program for stakeholders in the Institute.

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The Role of Policy in Tackling Plastic Waste in the Aquatic Environment

Susanna Gionfra, Clémentine Richer, and Emma Watkins

Contents

Abstract The release of plastic waste into aquatic environments, both fresh and sea waters, has been recognised as a major environmental problem due to the global nature of the issue and its ecological and socio-economic impacts. It is estimated that approximately 8 million tonnes of plastics are released into the world's oceans each year. The global nature of marine litter calls for actions to be undertaken at all levels and across all geographies.

While a number of policies and initiatives are in place to address the release of plastics to the environment, a growing accumulation is expected if further actions are not taken, with almost 250 million metric tonnes of plastics estimated to reach our oceans by 2050.

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Instruments which prevent plastic waste are particularly needed. These include actions to reduce the production and consumption of plastics, as well as encouraging reuse, recycling, and a better design of plastic products. Many plastic products, particularly those designed for single use, are vulnerable to enter the environment as litter and present a specific challenge for waste management.

At the European Union level, a range of policies is under development to target sustainability issues in relation to plastics, including their release into the aquatic environment. This relates closely to the EU's agenda on circular economy transition – providing one framework to support policy development.

This chapter explores the policy instruments that can be applied to tackle the issue of plastics in the aquatic environment. Examples include market-based instruments, regulations, information tools, and voluntary schemes. Particular attention will be given to market-based instruments, including taxes and fees used as a market signal to reduce the use of certain products, materials, and specific applications (e.g. packaging). In addition, instruments such as deposit-refund schemes and extended producer responsibility (EPR) schemes have been widely adopted presenting the potential to support the uptake, quality, and economics of recycling as well as reuse, therefore reducing litter. The chapter will cover revised EU waste legislation and targets, as well as the recently published EU Strategy on Plastics, as measures to encourage better management of plastic waste.

The chapter draws on evidence gathered within a number of studies carried out by the Institute for European Environmental Policy, which have covered policies addressing plastics, including specific research on the socio-economics of marine litter, market-based instruments (EPR schemes), port reception facilities, and packaging.

Keywords Aquatic environment, Circular economy, EU policy, Plastic pollution, Plastic waste

1 Introduction

Since the initial rise of plastics in the 1950s, this material has become commonplace in our everyday life. Plastics find applications in almost all sectors of society, from packaging to building and construction, automotive, electronic goods, agriculture, and others. However, the unprecedented growth witnessed by the plastic sector has resulted in significant environmental problems. Today, annual plastic waste generation in Europe has reached 26 million tonnes [1]. Globally, of the 6,300 million tonnes of plastic waste produced, only 9% is recycled, 12% incinerated, and 79% sent to landfills or leaked to the environment [2].

The increasing knowledge of the environmental implications of this material in recent years has led to growing efforts to support the transition towards a circular economy for plastics. However, due to their polymer and chemical composition,

plastics present a range of features that conflict with circular economy principles. On average, plastics contain 93% of polymer resin and 7% of additives [2]. The chemical composition hampers recyclability, thus creating obstacles to "closing the loop" on plastics, necessary to reduce the negative environmental externalities generated by the waste of this material. In addition, plastics are generally recycled through mechanical recycling, which leads to "downcycling", or recycling into lower-value applications, generating obstacles in the uptake of secondary raw materials. Plastics are also associated with short lifespans. It is estimated that 95% of the value of plastic packaging is lost to the economy after its first use, resulting in a loss of EUR 70–100 billion in material value per year [3].

The low rates of recycling and reuse of plastics and the high tendency to leak into the environment, together with the ease of fragmentation into smaller pieces and the short lifetime of plastic items, make this material highly damaging for the environment. Recently, growing awareness on the issue of plastic pollution in marine environments has led to a stronger emphasis on addressing its sources. Land-based sources constitute the principal source of marine litter (80%), while less originates from sea-based sources (20%) [4]. Today, it is estimated that approximately 8 million tonnes of plastics are released into the world's oceans each year [5]. Estimates indicate that between 150,000 and 500,000 tonnes of plastic litter reach the oceans from the EU each year [6]). In addition, plastics constitute 85% of marine litter, and 50% of litter found on beaches is composed of single-use plastics [7].

Improper waste management represents one of the key sources of plastic leakage into both the aquatic and terrestrial environments. For instance, it was estimated that in 2010, 12.7 million metric tonnes of plastic waste reached the oceans as a result of poor waste management in coastal areas [5]. In addition, increasing applications of plastics to sectors in direct contact with these environments, such as in agriculture, have led to an increase in plastic and microplastic pollution.

Microplastics are very small (<5 mm) particles, which can be intentionally added in products – such as the case of cosmetics – or result from residual plastic waste [8]. In both cases, microplastics leak into the environment, posing threats to biodiversity and potentially human health. Recent studies have found 20 microplastics per 10 g of human stools [9]. Indeed, only part of the 2–5% of plastics produced that finally reach the oceans are microplastics. In addition to affecting the aquatic environment, microplastic pollution is even more present in the terrestrial environment. In fact, microplastics in soil have been estimated to be between 4 to 23 times larger than in the oceans [10, 11].

It is estimated that approximately 63,000–430,000 and 44,000–300,000 tonnes of microplastics are released each year into the European and North American terrestrial environment, respectively, as a result of plastic application in agriculture, such as plastic films and sewage sludge used as fertiliser [12]. As a result, between 80,000 and 219,000 tonnes of microplastics enter the European marine environment each year, either through the fragmentation of macroplastics or through microplastics intentionally added in products, such as cosmetics [13]. Microplastics resulting from textile washing and cosmetic products also represent important sources of environmental pollution, as sewage treatment plants are not designed

to filter out these particles. It was estimated that around 700,000 fibres could be released from a wash load of 6 kg [14].

The global nature of plastic litter requires actions to be undertaken at all levels and across all territories. More recently, the damaging end-of-life impacts of plastics have been increasingly acknowledged by the international community, for example, in international and intergovernmental agreements such as the UNEA-2, UNEA-4, G7, G20, and UN Sustainable Development Goals [15]. At the European Union (EU) level, a range of policies is under development to target sustainability issues in relation to plastics, including their release into the aquatic environment. This relates closely to the EU's agenda on circular economy transition – providing one framework to support policy development.

2 EU Political Action on Plastics

At the EU level, efforts have recently been made on policy actions, backed by significant political involvement. Plastics were identified as one of the priority areas in the *EU Circular Economy Action Plan*, set out by the European Commission in 2015 as part of the Circular Economy Package [16]. The plan included a set of actions and measures directed at aiding the transition of Europe from a linear to a circular economy [17]. A recent report by the European Commission states that all 54 actions included in the plan have now been delivered or implemented [18].

As part of the Circular Economy Package, the European Commission made amendments to different *waste directives* (Waste Framework Directive; Landfill Directive; Packaging Directive; Directives on end-of-life vehicles, batteries and accumulators, and waste electrical and electronic equipment (WEEE)), which included the revision of waste management targets regarding recycling, reuse, and landfilling [19]. Among the revised targets, a specific recycling target for plastics was included, to reach 55% by 2030, as well as a target to reduce landfill to maximum 10% of the municipal waste by 2035 [20].

One of the commitments in the Circular Economy Action Plan was the creation of an *EU Strategy for Plastics*, which was adopted in 2018. The strategy represents the first set of measures addressing a single material – plastics [21]. With a list of actions to tackle the issue of plastic pollution, the strategy sets the way towards a "new plastics economy". Moreover, the strategy calls for multi-stakeholder engagement and sets objectives to transform the way plastic products are designed, produced, consumed, and disposed of. The actions and targets promoted by the strategy aim at achieving a systemic change by improving the economics and quality of plastics, curbing plastic waste and littering, driving investments and innovation, and harnessing global action [22]. For instance, a key target set in the strategy is for all plastic packaging placed on the EU market to be reusable or recyclable by 2030 [17, 18].

Box 1 Key Objectives of the EU Strategy for Plastics in a Circular Economy [23]

Key Objectives for the EU to Achieve

- All plastic packaging should be reusable or recyclable in a cost-effective way by 2030.
- Over 50% of plastics waste generated in the EU should be recycled by 2030.
- Fourfold increase in sorting and recycling capacity and improved separate collection by 2030.
- Fourfold increase in demand for recycled plastics, allowed by the establishment of a dedicated market.
- Greater use of innovative materials and sustainable alternative feedstocks for plastic production, moving away from fossil fuels.
- Increased use of circular solutions for plastic waste prevention, i.e. alternatives to disposable plastics.
- A "drastic" decrease in the leakage of plastics into the environment.
- The EU to have a leading role at the global level on plastic waste and pollution.

Together with the Plastics Strategy, three other initiatives were adopted:

- A *new Directive on Port Reception Facilities* was adopted to tackle sea-based marine litter, which is mostly composed of plastics. The objective of the new proposal is to limit and control discharges of waste and adapt port facilities for waste collection. Measures include the establishment of a flat fee for waste from ships [17].
- A *Communication on the Interface Between Chemicals, Products and Waste Legislation*, exploring issues and links between legislation on chemicals, products, and waste and their impact on a circular economy [24].
- A *Monitoring Framework for the Circular Economy*, consisting of ten indicators grouped in four areas of the circular economy (production and consumption, waste management, secondary raw materials, competitiveness and innovation). The monitoring framework should assess progress, effectiveness of measures, and cases of best practices [25].

The instrument that should contribute most to the aims of the Plastics Strategy is the *Directive on Single-Use Plastics (SUP)*[1] which, as the name suggests, is aimed at tackling specifically single-use items made of plastics, which make up 70% of the marine litter according to the European Commission [26]. The directive came about as a result of recent studies which contributed to significantly improving the scientific knowledge on the current status of litter. A list of top ten items found

[1]Directive (EU) 2019/904 Directive on the reduction of the impact of certain plastic products on the environment.

on beaches led the way to the creation of a list of measures addressing those items, which most represent a threat to the environment. These products, which include, for instance, cotton buds, straws, and cutlery, make up a significant part of marine litter. The European Commission published its proposal in May 2018, which was formally adopted by the European Parliament on 27th March 2019. The main provisions are explained in Box 2. These include a ban of those single-use plastic products which already have non-plastic alternatives by 2021 and 90% collection target for plastic bottles by 2029, as well as a focus on the polluter pays principle, thus increasing producer responsibility [26–28].

Box 2 Key Measures in the SUP Directive [29, 30]
The SUP Directive includes:

- A EU-wide ban on several SUP products including plastic cotton buds, straws, beverage stirrers, balloon sticks, oxo-degradable plastics, expanded polystyrene food containers and cups, as well as plates and cutlery (with exemptions until 2023).
- EU Member States should adopt measures aiming at a 25% reduction of consumption of SUP products as food containers and cups.
- Member States will have to take awareness-raising measures for citizens about plastic litter. There will also be an obligation to label products, warning about chemicals in SUP products and their negative impacts, as well as available reuse options. It is also mandatory to prevent the use of hazardous chemicals in sanitary products.
- Extended producer responsibility (EPR) schemes for cleaning up as well as establishing awareness-raising measures.
- Target to separately collect 90% of beverage containers, which should be produced from 35% of recycled materials by 2025.
- Member States have the obligation to reduce post-consumption waste from tobacco product filters that contain plastics, by 50% by 2025 and 80% by 2030.
- Specific measures on fishing gear, including harmonised standards and an EPR scheme, and targets of 50% collection and 15% recycling by 2025.

3 Instruments

EU actions on plastics have had particular focus on recycling until present. Increasing the rate of recycling of plastics can have important positive implications on the environment as well as on the economy. A study by Trucost estimated that if plastic packaging recycling and landfilling were to reach, respectively, 55% and 10% in the EU and North America, the environmental costs associated with plastics would fall by US $4.8 billion per year [31]. While representing an important waste management strategy, other strategies are preferred if the aim is to

close the loop on plastics and reach a circular plastic economy. EU waste management is guided through the Waste Framework Directive, which sets a specific hierarchy for the management of waste. By applying this hierarchy, actions of prevention and reuse are prioritised.

The issue of plastic pollution calls for actions to be implemented at all steps of the waste hierarchy, but priority should be given to those actions which can tackle the problem at its source. "Closing the tap on plastic" requires efforts not only to manage waste appropriately but also to prevent it and reduce the amount of often unnecessary plastics placed on the market. Indeed, it is important to stress the importance of the priority of reducing society's reliance on plastics. Once this is done, we can also focus on making sure that the plastics that are used are designed in such a way that their sustainability is supported. The design stage is of crucial importance as it is at this stage that decisions upon the recyclability, reusability, and reparability of plastics are made and therefore paramount to determine the end-of-life treatment and potential secondary uses of a product.

Policy tools applied with the intention of improving the sustainability of the plastics that are placed on the market will result in better end-of-life management and reduced plastic leakage into the environment. Policy approaches of this kind can be of a regulatory nature, market-based, information and voluntary tools, as well as financing and investment.

3.1 Regulations

Regulatory action is a central tool to tackle plastic pollution, and an increasing number of regulations have been put in place with this objective.

With the aforementioned EU Directive on Single-Use Plastics, the EU is the first region to introduce new laws aimed at reducing single-use plastics and their associated environmental impacts. While several Member States have already implemented national laws to ban certain single-use plastic products, all EU national governments will have to transpose the rules adopted with the Directive into their national laws until 2021 (see Box 3 below).

Box 3 National Level Restrictions on Plastic Products

Italy, Ban on Cotton Buds

In January 2019, Italy put in force a ban on the production and sale of non-biodegradable or compostable cotton buds. The ban was first introduced in the Budget Law in 2017. Cotton buds represent 9% of litter found on Italian beaches, therefore significantly contributing to marine litter. With this new rule, Italy is the first country in the EU to implement a ban on these single-use plastic items [32, 33].

(continued)

Box 3 (continued)

France, Plastic Plates, Cups, and Cutlery

In 2016, France announced its plan to ban all single-use plastic plates, cups, and cutlery by 2020. The law follows the ban on single-use plastic bags in the country, and they are both part of France's Energy Transition for Green Growth Act [34, 35].

Regulatory measures have also been applied to specific applications, such as microplastics in cosmetics. A ban on microplastics in specific consumer products has been adopted by several countries, both in the EU and beyond (see Box 4 below). In addition, in January 2019, the European Chemicals Agency (ECHA) submitted a proposal for the restriction of intentionally added microplastics. The agency estimates that the adoption of the proposal, which is part of the EU Plastics Strategy, could reduce the amount of microplastics leaked into the natural environment at the EU level by approximately 400,000 tonnes in 20 years [36]. The restriction is expected to become a law across Europe by 2020.

Box 4 National Bans on Microplastics

A set of national regulations addressing microplastics has arisen as a result of the increasing knowledge on the harmful impacts of these particles.

The first country to introduce a ban on microbeads in cosmetics was the Netherlands in 2014. Similar bans have been introduced by the UK, Sweden, Taiwan, Canada, the USA, New Zealand, and Australia.

Italy also announced a ban on the sale of cosmetics containing microbeads, to come into effect in January 2020 [37].

3.2 Market-Based Instruments

Market-based instruments are widely used to address environmental issues as they provide a way to trigger behavioural change and drive businesses towards more sustainable models [38]. Market-based instruments applied in the plastic context include taxes and fees, subsidies, and extended producer responsibility.

3.2.1 Taxes and Fees

Taxes and fees are generally applied to specific products, materials, or applications. These instruments are designed to internalise environmental costs and, by increasing the cost of polluting products or activities, create signalling effects and encourage a reduction in the consumption and/or production of the taxed good or activity [39, 40].

Several EU Member States have put in place taxes on plastic items such as packaging which is the biggest application of plastics. In some cases, fees were increased when applied to specific types of plastics or items (e.g. single use).

Box 5 Plastic Packaging Tax, UK

In 2018, the UK government announced the intention to introduce a plastic packaging tax. The tax, currently subject to consultation, should come into force in 2022 and should target the production and import of plastic packaging with less than 30% of recycled content. The consumption of plastic packaging in the UK is considerably high, with 2 million tonnes of plastic packaging used each year. Plastic packaging accounts for 67% of the UK plastic waste and 44% of the total plastics used in the country.

The proposed tax aims to increase the use of recycled plastics and incentivise more sustainable packaging [41, 42].

In addition to taxing specific products, environmental taxes can be applied to reduce polluting activities. For instance, taxes on landfilling encourage alternative, more sustainable waste management strategies such as recycling. A landfill tax on waste disposal is currently applied in 24 EU Member States [43]. As part of the Circular Economy Package, a proposal to amend the EU Landfill Directive was brought forward, and, when it enters into force, it will prohibit the landfilling of selectively collected waste [44].

In 2018, a "plastic tax" was proposed by the EU Budget Commissioner and included in the proposals for the EU's budget for 2021–2027. The suggested plastic-related tax would impose on EU Member States a fee of €0.80 per kg of nonrecycled plastic packaging waste. The estimated revenue to be raised through the tax is €7 billion in revenues from 2021–2027 [45, 46].

3.2.2 Extended Producer Responsibility (EPR)

Extended producer responsibility schemes follow the polluter pays principle and, by definition, shift the responsibility for some of the negative environmental externalities associated with a product, and therefore the costs, to the producers. Such responsibility can either be individual, if borne by the producer for its products, or collective, if a group of producers pay a fee to be part of a producer responsibility organisation (PRO). EPR has two main objectives: (1) to incentivise resource-efficient and sustainable design of products and (2) to ensure effective end-of-life collection and treatment and improve reuse and recycling. In order to reach these two objectives, EPR schemes need to incentivise change at the design stage.

In the EU, several EPR schemes are applied to different product groups. In the context of plastics, EPR schemes on packaging are widely applied. All these schemes are based on basic fee modulation which imposes a differentiated

fee depending on the material of the packaging placed on the market. In general, plastic packaging is subject to higher fees compared to other materials. While many EPR schemes have been successful in improving waste management and increasing recycling, their impacts on product design have not been significant [47].

Some schemes are based on eco-modulation of fees which offer the potential to drive change in production by encouraging producers to include eco-criteria in the manufacturing stage. Examples of schemes of this kind include the French CITEO scheme, based on a bonus-malus system, and the Italian CONAI (see Box 6 below). Nevertheless, wider and more advanced EPR schemes based on eco-modulation can make an important contribution to encourage producers to design their products more sustainably, taking into consideration criteria of circular principles which could more significantly influence the end-of-life treatment [47].

Box 6 Modulation of Fees: CONAI, Italy

The Italian extended producer organisation (PRO) CONAI (National Packaging Consortium) established an EPR scheme applied to all types of packaging including plastics. The model is based on a self-financing system and on an environmental contribution which is charged to the producers and packaging importers. The level of the financial contribution is set based on the type of material and on the amount (in tonnes) placed on the market. In 2018, CONAI introduced a Plastic Packaging Contribution Diversification which set the basis for the modulation of fees. The difference between fees is dictated by how recyclable and sortable the different types of plastic packaging are, with higher fees imposed if the packaging does not have these characteristics [48]:

Level A: sortable and recyclable packaging from the Commerce and Industry circuit

Level B: sortable and recyclable packaging from the Household circuit

Level C: packaging not sortable/recyclable with current technologies

In addition to packaging, EPR schemes are applied to several product groups, many of which contribute to macro- and microplastic pollution. Therefore, implementing these schemes on those product groups which most represent a threat to the environment due to their design – such as textiles and agricultural films – will contribute to tackling the plastic pollution issue.

As regards the textile sector, only one EPR is currently in place in France. The textile sector is a significant contributor to the plastic pollution problem and still operates on an almost entirely linear system. While the French EPR scheme (ECO-TLC) has led to some improvements, a number of challenges that reflect the complexity of the sector have made EPR schemes widely unpopular within this industry. For example, the lack of proper sorting and separation technologies is a clear barrier, and addressing this is a priority before the establishment of similar schemes [49].

Market-based instruments can contribute to bringing forward the implementation of legislation, including the achievement of existing EU waste targets as well as those in the Circular Economy Package. In addition, economic instruments of this kind, if properly implemented, offer the potential to reach broader environmental and circular economy objectives, including reducing natural resource depletion, GHG emissions, and leakage into terrestrial and aquatic environments.

3.3 Financing and Investment

Financing is crucial for research and innovation in the context of plastics, as many innovating technologies are emerging in this area. Examples include cleaning and litter transformation technologies as well as innovation in materials, such as bio-based and biodegradable plastics. Nevertheless, innovations related to plastics still present knowledge gaps, including on associated costs and benefits, as well as more general knowledge on sources and pathways. Financing research can help in bridging these gaps which need to be addressed in order to ensure sensitive investments [50]. As part of Horizon2020, the EU's research and innovation funding programme, EUR 250 million have been spent on projects in the field of plastics. Since 2018, for the remaining years of Horizon2020, EUR 100 million have been granted to research directly related to the Plastics Strategy [51].

3.3.1 Waste Management Infrastructure

Financing and investments in waste management infrastructure can lead to significant improvements in the treatment of plastic waste. Indeed, improper waste management represents one of the key sources of plastic leakage into the environment. For instance, it was estimated that in 2010, 12.7 million metric tonnes of plastic waste reached the oceans as a result of poor waste management in coastal areas [5]. Therefore, investments in infrastructure can provide an important and necessary contribution to increasing the rate of recovery and lessening the harmful implications of a lack of appropriate waste management.

The application of other instruments, both market-based and regulatory, which aim at aiding the transition to a circular plastic economy, can support the improvement of waste management strategies. These tools will prioritise cleaner and more sustainable management of waste such as reuse and recycling, rather than landfilling and incineration. Incentives of this kind encourage financing and investments in specific waste management infrastructure – reverse logistics, collection, sorting, cleaning facilities, and treatment – which are necessary to meet environmental objectives. Nonetheless, none of the existing policy instruments will be as effective in the absence of proper waste management infrastructure. Such a relationship stresses the importance of financing and investments in the quest for ending plastic pollution [52]. The textile sector provides a clear example

of such interrelation. In the absence of proper waste management infrastructure, and more specifically solutions for textile sorting and recycling, EPR schemes, which incentivise recycling, might generate adverse effects and result in an increase of textile waste [49].

In addition to improving the treatment of waste, financing and investments can also contribute to reducing the gaps and inequities that exist in waste management infrastructure across different countries. Such inequities create divergence in the waste management performance as well as confusion among citizens. Improving infrastructure within and across countries can therefore result in reduced risks of plastic leakage into the environment [5].

3.3.2 Green Public Procurement

Public budgets can drive significant investments for the development of sustainable and circular services and products. Several municipal authorities have introduced measures aimed at "greening" public procurement [15]. In the EU, public authorities spend €2 trillion each year, equivalent to 19% of its GDP [53]. Indeed, introducing environmental requirements or criteria in public procurement can contribute to reducing the environmental impact of products or services [54]. While a voluntary instrument, Green Public Procurement (GPP) plays a central role in stimulating demand for and innovation in more sustainable goods and services and therefore in increasing the resource efficiency of the EU's economy [55]. In the context of plastics, GPP can impact different steps of the value chain – from limiting consumption of particularly harmful items (e.g. single-use plastics) to promoting more sustainably designed products and incentivising good waste management practices [56].

Box 7 GPP Criteria for Plastics: Cities in Action

Several municipal authorities have introduced GPP criteria for plastics.

The city of Hamburg (Germany) introduced in 2016 GPP rules to ban the use – at the municipal level – of coffee capsules, as well as single-use bottles and other items [57].

Another example is given by the city of Turin (Italy) which introduced, in 2013, GPP rules on school catering contracts to encourage separate collection of waste and the use of reusable and refillable packaging. It was estimated that shifting to reusable plates led to 157 tonnes less of plastic waste per year [58].

3.4 Information and Voluntary

3.4.1 Voluntary Commitments

The growing awareness about environmental impacts of plastics and regulations to address these has led to an increasing number of companies to integrate such concerns in their business strategies through voluntary commitments. While not as powerful as instruments of compulsory nature, voluntary commitments can drive significant and ambitious changes across the plastic value chain.

An example of a company which has committed to improving the sustainability of plastics used in its processes is IKEA. The commitment entails ensuring that all plastics in their products are 100% recyclable and renewable by 2020 [59]. Similarly, Unilever, which is associated with a significant use of plastic packaging, committed to use only plastic packaging that is reusable, recyclable, or compostable by 2025 [60]. However, while such commitments are welcome, they may only be effective if there are systems in place for collection, separation, and recycling of these different recycling and compostable waste fractions for domestic and commercial waste.

Regulators can play an important role in stimulating commitments of this kind from the private sector. For instance, as part of the Plastics Strategy, the European Commission launched a "pledging campaign" which encouraged companies to put forward voluntary pledges to use or produce more recycled plastics, with the overall objective of bridging the gap between the supply and demand for recycled plastics and boosting their uptake [61]. The commitments expressed by industries through the pledging campaign will ensure an increase of the market for recycled plastics by 60% by 2025 [62].

In December 2018, the European Commission also launched the Circular Plastics Alliance which, as the name indicates, promotes voluntary action by industries to move towards more circular plastics. The Alliance gathers the key stakeholders in the plastic value chain and has the overarching objective of reaching 10 million tonnes of recycled plastics in European products by 2025 [63]. However, more ambitious commitments will be needed to achieve the objective.

Innovative initiatives have arisen promoting business models based on renouncing packaging and supporting the use of reusable or non-plastic solutions (e.g. through selling loose products). Initiatives of this kind have witnessed a significant growth among food retailers, which have normally been associated with high levels of packaging waste. These new zero-waste or circular models, often coupled with the objective of reducing food waste, offer the potential to drive important changes in consumers' trends and preferences, contributing to the reduction of plastic packaging waste and therefore alleviating the associated threats to the natural environment. The rise of these types of initiatives and the uptake of alternative, less wasteful consumption patterns both indicate and result from an increasing public support towards environmentally conscious actions [64].

In addition to greater awareness about current environmental challenges and their consequences, such an increase in acceptance also results to a great extent from increasing political action and support. The aforementioned policy instruments which have been developed in the EU and beyond with the objective of improving the sustainability of plastics and reducing their harmful impacts on the environment are the proof of such incremental political support. However, further political support is needed to make such innovative initiatives and business models mainstream.

Indeed, citizens' engagement in voluntary activities which have environmental objectives has radically increased in recent years. Examples also include national-level clean-up activities, which are carried out on polluted beaches, or in environments surrounding riverine areas.

3.4.2 Information Tools

Information tools in the context of plastics are developed with the objective of facilitating the flow of information across the different steps of the value chain. Such tools can address consumers in order to enable them to make better informed purchasing choices. Examples include product environmental labels, environmental product declarations, as well as app-based tools. Increasing access to information at the purchasing stage can lead consumers to buy less harmful products and consequently share information about consumers' preferences, sending a market signal upstream, to producers and designers [65]

Box 8 AskREACH
The European app "AskREACH" provides a way to consumers to receive on-the-spot information by submitting requests to suppliers and asking about the substances of very high concern (SVHC), which are contained in their products. The app facilitates the "right to know" provision included in the EU REACH regulation, Article 33 [66].

An example of where increasing the flow of information can have important implications on the extent of plastics reaching the environment, especially the aquatic environment, is the disclosure of information regarding the presence or absence of microplastics in products, such as cosmetics.

Box 9 Beat the Microbead App
Beat the Microbead app was developed by the North Sea Foundation and Plastic Soup Foundation to enable consumers to verify whether a product contains plastic microbeads. This is done by scanning the barcode of the

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Box 9 (continued)
product with their smartphone camera through the app. The app was initiated through the "Beat the Microbead" campaign, launched by the Plastic Soup Foundation in 2012 and sponsored by the UN [67].

4 Conclusion

Action on plastics in the EU has witnessed significantly increased political and public attention, which has resulted in the adoption of a range of measures, such as new regulations, market-based instruments, voluntary commitments, and investments. However, the issue of plastic pollution and leakage into the aquatic environment derives from the unprecedented growth in global plastic production, as well as from our unsustainable consumption patterns. These trends, coupled with the sustainability challenges associated with this material, have made plastics a ubiquitous part of our lives. Tackling this requires actions to be undertaken at all levels and all geographies. As with climate change, plastic pollution is a global problem that does not know borders and therefore requires a global solution. This chapter has provided an overview of the crucial role of policy in bringing about solutions to this problem.

While many of the policy instruments currently in place in the EU have been adopted to power the transition to a resource-efficient Europe, some lack an alignment with key circular economy principles. Indeed, by reviewing the EU political action on plastics, it is clear that a particular focus has been dedicated to recycling. From a waste hierarchy perspective, recycling does not represent the preferred option, which should be prevention and reuse. While there are important economic and environmental benefits, a focus on plastic recycling misses the opportunity to tackle the issue at its source. Ongoing discussions on what is needed to "close the loop" on plastics have in fact prioritised actions revolved towards preventing plastic waste or increasing its reusability, reparability, and durability. Several policy measures currently in place can provide powerful tools to incentivise these actions, especially by supporting changes at the design stage. The European Commission has estimated that the design stage determines 80% of the environmental impact of products. In the context of plastics, more sustainable design choices can have important implications for the end-of-life stage of products and significantly reduce plastic leakage into the natural environment. With 8 million tonnes of plastics currently entering our oceans each year, this systemic change is needed now more than ever.

The picture provided by the overall EU political action on plastics emphasises the increasing knowledge gained on the sources and pathways of plastic waste as well as the key role played by policy in tackling plastic pollution in the aquatic environment. Nonetheless, many of the policy instruments in place present challenges or weaknesses that prevent them from effectively tackling

plastic pollution. In addition, the diverse instruments currently in place and their effective or potential impact indicate the need to consider a broad range of measures to be applied as part of a policy mix, rather than seeking a one-fit-for-all solution.

Wider ambitions and better implementation are needed to trigger the required change. A clear example is given by extended producer responsibility schemes. While conceptually very powerful, none of the current EPR schemes applied to packaging have been used to their full potential, and, despite some beneficial effects, they have failed to deliver significant impacts at the design stage and have largely focused on recycling. Several improvements need to be made and much more can be done to make the EU policy mix effectively target the sustainability issues in relation to plastics, including their release into the aquatic environment, as well as to better align policies with circularity principles.

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Monitoring Approaches for Marine Litter in the European Sea Basins

Daniel González-Fernández and Georg Hanke

Contents

Abstract This chapter describes the monitoring approaches used by marine environmental management frameworks for the assessment of plastic pollution in the European sea basins: Mediterranean Sea, Black Sea, Baltic Sea and the North-East Atlantic region including the North Sea. We review the current developments in the implementation of monitoring elements under the European Marine Strategy Framework Directive and the four related Regional Sea Conventions: OSPAR Commission, HELCOM, Black Sea Commission and UNEP/MAP Barcelona Convention. The analysis of the existing monitoring approaches reveals strong commitments to providing common monitoring elements for the assessment of marine litter across the different management frameworks and, consequently, between neighbouring countries. Although these monitoring approaches rely mostly on a series of common monitoring elements, the implementation of such approaches is recent and remains subject to relevant knowledge and data gaps. Nevertheless, interaction and coordination among management frameworks will provide substantial improvements to achieving coherent and comparable assessments for marine litter and plastic pollution across Europe in the coming years. The process of developing and

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implementing monitoring approaches at the European scale through international cooperation is an excellent source of knowledge and experience for the scientific community and policy-makers on a global scale.

Keywords Europe, Marine litter, Monitoring, MSFD, Plastic pollution, Regional Sea Conventions

Abbreviations

BITS	Baltic International Trawl Surveys
BSAP	Baltic Sea Action Plan
BSC	Black Sea Commission on the Protection of the Black Sea Against Pollution
BSIMAP	Black Sea Integrated Monitoring and Assessment Program
CEMP	Coordinated Environmental Monitoring Programme (OSPAR)
COM DEC	Commission Decision (EU) 2017/848
EC	European Commission
EcAp	Ecosystem Approach
EcoQO	Ecological Quality Objective
EO	Ecological Objective
EU	European Union
GES	Good Environmental Status (MSFD)
HELCOM GEAR	HELCOM Group for the Implementation of the Ecosystem-Based Approach
HELCOM	Helsinki Commission – Baltic Marine Environment Protection Commission
IBTS	International Bottom Trawl Survey
IMAP	Integrated Monitoring and Assessment Programme of the Mediterranean Sea (UNEP/MAP)
JAMP	Joint Assessment & Monitoring Programme (OSPAR)
JRC	Joint Research Centre (EC)
MEDITS	International Bottom Trawl Survey in the Mediterranean
MS	Member State (EU)
MSFD	Marine Strategy Framework Directive (2008/56/EC)
NMDMP	US National Marine Debris Monitoring Program
OSPAR	Oslo and Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
RSC	Regional Seas Convention
TG ML	Technical Group on Marine Litter (MSFD)
UNEP/MAP	United Nations Environment Programme/Mediterranean Action Plan to the Barcelona Convention

1 Introduction

The study of plastic pollution in marine environments, driven by environmental, legal and regulatory aspects, has recently become a research topic of significant interest. Since the 1950s, the mass production of plastic for daily use products has grown exponentially, contributing to the increasing amount of plastic items available to accumulate in our seas [1]. The presence of plastics in the marine environment raised researchers' interest, evolving from scattered studies in the 1970s [2–4] to a sharp rise in number of publications in the last 10 years [5]. It is in the early 2000s when, triggered by research publications on floating plastics at open sea [6, 7], marine litter started becoming a high-profile issue, reaching the general public and raising awareness worldwide [1]. This general concern about plastic pollution, and particularly microplastics (particles <5 mm), along with attention received from administrations and research funding schemes, is also rapidly expanding and transferring its scope from the marine to the fresh water environmental compartments and beyond. For example, the first study on atmospheric microplastics transport and deposition into remote areas has been published recently by Allen et al. [8]. Nevertheless, the majority of plastic pollution research is focused on the marine environment, where routine monitoring programmes have been concentrated so far.

Monitoring of marine litter started initially as small-scale activities, describing methodologies for assessment of floating litter, and more extensively beach litter surveys, the latter being the most suitable method for large-scale data collection [9]. First large-scale marine litter monitoring programmes refer to beach litter data acquired along the US coast during the development and implementation of the US National Marine Debris Monitoring Program (NMDMP) in the period 1996–2006 [10], or the international OSPAR Commission for the North-East Atlantic region, performing regular surveys of beach litter pollution since 2001 [11]. Gradually, several national and international institutions have been planning or have already implemented regular monitoring programmes, considering not only beaches but also floating (water surface layer), seafloor and marine biota as compartments in their marine litter assessments [1, 12–14]. In Europe, the Marine Strategy Framework Directive (MSFD) [15] and the four Regional Sea Conventions (RSCs), OSPAR Commission for the North-East Atlantic region [16], HELCOM (Helsinki Commission – Baltic Marine Environment Protection Commission) [17], Black Sea Commission (BSC) [18] and UNEP/MAP Barcelona Convention for the Mediterranean Sea [19], are providing frameworks for large-scale actions against marine litter.

Monitoring programmes are aimed at providing scientific evidence for the assessment of the environmental status and achievement of the objectives set in the environmental targets. The purpose of monitoring includes assessing the possible impact of marine litter and its extent, facilitating the selection of mitigation measures to reduce inputs and evaluating the effectiveness of such measures [20].

However, due to the only recent start of monitoring/measuring plastics in marine environments, there are still significant data and knowledge gaps. The development

of agreed methodologies for collection of consistent field data is still in its infancy, hindering the harmonization, coherence and comparability of monitoring and assessment approaches. At the same time, the growing number of research initiatives in the field is producing a diversification of methodologies that can impact, both positively and negatively, the development of monitoring approaches. On the one hand, diversification can help fulfil the purpose of monitoring under demanding and changing priorities coming from environmental, societal and policy perspectives. On the other hand, if coordination and cooperation are not taken into account, diversification can result in noncomparable assessments, limiting the potential of monitoring activities at different geographical scales.

Nevertheless, it is evident that public and social awareness is pushing the scientific and policy efforts forwards in order to achieve prevention, mitigation, removal and behavioural change with regard to marine litter [14]. In this context, sometimes subject to bridging basic data and knowledge gaps, implementation of monitoring programmes plays a key role in the process of controlling plastic pollution.

In this chapter, we describe and discuss the marine litter monitoring approach developed by the MSFD and its interactions with the RSCs across the four European sea basins, as a major scenario for the establishment of coordinated and harmonized monitoring approaches, enabling comparable assessments at a transnational level.

2 The Marine Strategy Framework Directive: Descriptor 10 – Marine Litter

The MSFD, Directive 2008/56/EC [15], is intended to achieve or maintain Good Environmental Status (GES) in EU marine waters. It is a policy framework for 23 coastal Member States (MS) of the European Union (EU) with sea borders in the four European seas: Mediterranean Sea, Black Sea, Baltic Sea and North-East Atlantic region (Fig. 1), extending to a 68,000-km-long coastline [21]. The MSFD is based on an ecosystem-based approach to the protection and sustainable use of the marine environment, and regular reporting based on a 6-year implementation cycle, which includes assessing the establishment and implementation of coordinated monitoring programmes (MSFD Article 11). This directive considers 11 qualitative descriptors for the holistic assessment of the environmental status. For each descriptor, specific criteria and methodological standards on GES and specifications and standardized methods for monitoring and assessment are laid down in Commission Decision (EU) 2017/848 (COM DEC) [22].

Regarding plastic pollution, the MSFD includes Descriptor 10, ‘Properties and quantities of marine litter do not cause harm to the coastal and marine environment’ (short name: Marine Litter, D10). Since there was a limited background available for this descriptor at the EU scale, the MSFD Technical Group on Marine Litter (TG ML) was formed within the implementation process of the MSFD and is chaired

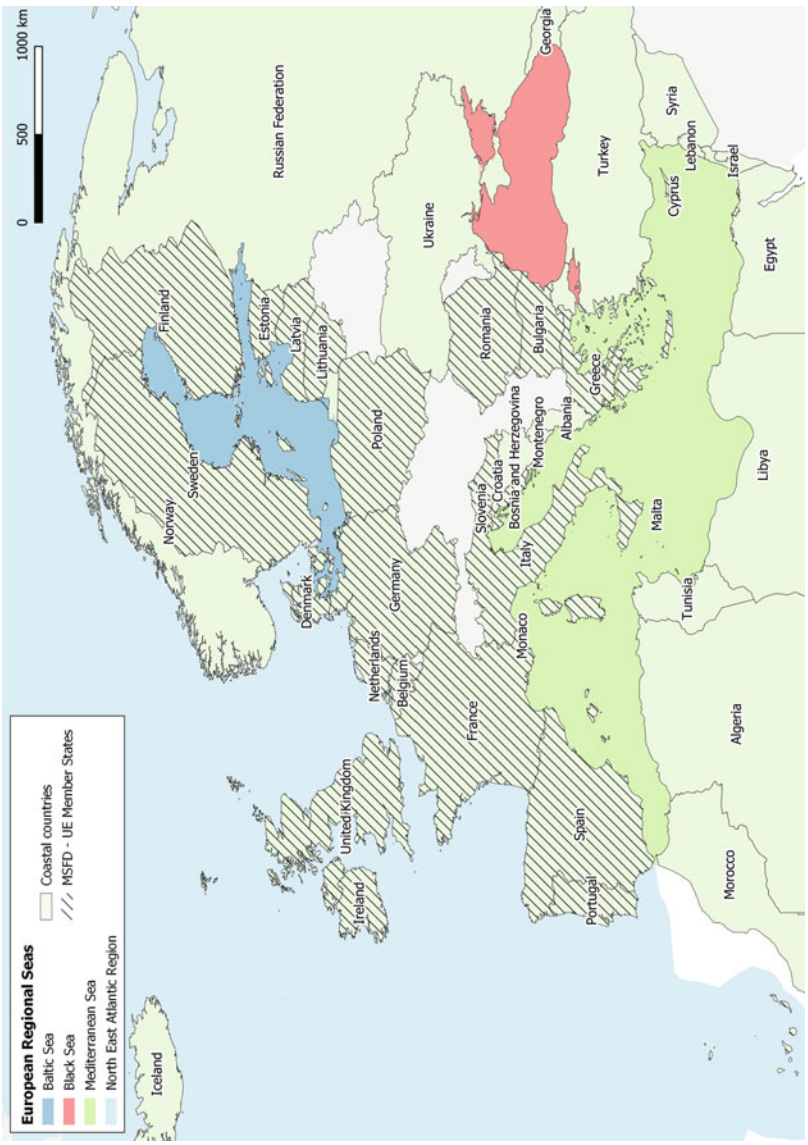

Fig. 1 Coastal countries in the four regional seas bordering the EU, including Member States involved in the MSFD. (regional seas limits extracted from EEA [23])

by Ifremer, the German Environmental Agency and the European Commission (EC) Joint Research Centre (JRC). This group has produced several reports offering recommendations and guidance to MS and beyond [24], including the *Guidance on Monitoring of Marine Litter in European Seas* [25], which has been a key document for many MS where regular monitoring did not exist during the first implementation cycle of the MSFD (2012–2018). This guidance document described general approaches and strategies for marine litter monitoring relevant to the MSFD and provided guidance to monitoring litter deposited on the beach, on the water surface, on the seafloor and in biota (ingestion and other interactions, such as entanglement) and microplastics (in the marine environment and biota). Size categories were differentiated into micro- (<5 mm), meso- (5-25 mm) and macro- (>25 mm) litter. Furthermore, it proposed a harmonized list for classification of marine litter, which has recently been reviewed: the Joint List of Litter Categories. Currently, this guidance document is under review for updates, considering latest research developments and adapting to the specifications included for the monitoring and assessment of marine litter in the new COM DEC [22].

Table 1 includes the criteria (C) to be considered by MS in Descriptor 10 [22]. Primary criteria, established at the EU level, consider composition, amount and spatial distribution of litter (meso- (5–25 mm) and macro- (>25 mm)) for D10C1 and micro-litter (<5 mm) for D10C2. Secondary criteria, to be established through regional collaboration, refer to the amount of litter and micro-litter ingested by marine animals for D10C3 and the number of individuals per species adversely affected by entanglement and other adverse effects for D10C4. Specifications and standardized methods under D10C1 require monitoring litter on the coastline (unit: number of items per 100 m of coastline length) and the possibility to include litter floating in the surface water of the water column and deposited on the seabed (unit: number of items per square kilometre, for both compartments). In the case of D10C2, monitoring is required for micro-litter in the surface layer of the water column (units: number of particles and weight in grams per square metre) and in the seabed sediments (units: number of particles and weight in grams per kilogram (dry weight) of sediment), while the coastline compartment could be an additional option (units: same as for seabed sediment). For the secondary criteria, monitoring may be based on incidental occurrence of animals being affected by marine litter (see details in Table 2) and the units to be used: grams of litter/micro-litter and number of items per individual (for each species and in relation to individuals' size) for D10C3 and number of individuals with lethal or sublethal impacts per species for D10C4.

COM DEC 2017/848/EC [22] provides for MS to establish threshold values for assessment of GES, through EU, regional or subregional cooperation. Threshold setting requires the availability of a well-established monitoring framework. The set-up of monitoring approaches, collection of data for baseline analysis and the development of thresholds are done in collaboration among MS and RSCs within the TG ML [24].

Table 1 MSFD Descriptor 10 – Marine Litter: criteria, specifications and standardized methods for monitoring and assessment. Adapted from the Commission Decision (EU) 2017/848 [22] (Methodological standards, scale of assessment and use of criteria for assessment, have not been included)

	Criteria description[a]	Criteria element (litter categories[b])	Specifications and standardized methods for monitoring and assessment	Units of measurement
Primary criteria				
D10C1	The composition, amount and spatial distribution of litter, on the coastline, in the surface layer of the water column and on the seabed, are at levels that do not cause harm to the coastal and marine environment	Litter (excluding micro-litter), classified in the following categories: artificial polymer materials, rubber, cloth/textile, paper/cardboard, processed/worked wood, metal, glass/ceramics, chemicals, undefined and food waste[c]	Litter shall be monitored on the coastline and may additionally be monitored in the surface layer of the water column and on the seabed. Information on the source and pathway of the litter shall be collected, where feasible	Amount of litter per category in number of items: – Per 100 m (m) on the coastline – Per square kilometre (km) for surface layer of the water column and for seabed
D10C2	The composition, amount and spatial distribution of micro-litter, on the coastline, in the surface layer of the water column and in seabed sediment, are at levels that do not cause harm to the coastal and marine environment	Micro-litter (particles <5 mm), classified in the categories 'artificial polymer materials' and 'other'	Micro-litter shall be monitored in the surface layer of the water column and in the seabed sediment and may additionally be monitored on the coastline. Micro-litter shall be monitored in a manner that can be related to point sources for inputs (such as harbours, marinas, wastewater treatment plants, stormwater effluents), where feasible	Amount of micro-litter per category in number of items and weight in grams (g): – Per square metre (m) for surface layer of the water column – Per kilogram (dry weight) (kg) of sediment for the coastline and for seabed
Secondary criteria				
D10C3	The amount of litter and micro-litter ingested by marine animals is at a level that does not adversely affect the health of the species concerned	Litter and micro-litter classified in the categories 'artificial polymer materials' and 'other', assessed in any species from the following	The monitoring may be based on incidental occurrences (e.g. stranding of dead animals, entangled animals in breeding	Amount of litter/micro-litter in grams (g) and number of items per individual for each species in relation to size (weight or length,

(continued)

Table 1 (continued)

	Criteria description[a]	Criteria element (litter categories[b])	Specifications and standardized methods for monitoring and assessment	Units of measurement
		groups: birds, mammals, reptiles, fish or invertebrates[d]	colonies, affected individuals per survey)	as appropriate) of the individual sampled
D10C4	The number of individuals of each species which are adversely affected due to litter, such as by entanglement, other types of injury or mortality or health effects	Species of birds, mammals, reptiles, fish or invertebrates which are at risk from litter[d]	S*ame as for D10C3*	Number of individuals affected (lethal; sublethal) per species

[a]For all criteria, Member States shall establish threshold values for these levels through cooperation at the Union level, taking into account regional or subregional specificities
[b]According to 'Level 1 – Material' categories from the Master List of categories of litter item [25]
[c]Member States shall establish that list of species to be assessed through regional or subregional cooperation
[d]Member States may define further subcategories

3 Regional Sea Conventions

The MSFD foresees regional cooperation in order to ensure coordination among MS, but also between EU and non-EU countries, developing actions through existing institutional structures such as the four RSCs: OSPAR, HELCOM, UNEP/MAP and BSC. The cooperation between MSFD and the RSCs involves 41 coastal countries, 23 EU and 18 non-EU (Fig. 1), presenting different situations depending on the region (Fig. 2). In the North-East Atlantic and the Baltic Sea, most of the RSCs contracting parties are also MSFD MS: 10 out 12 countries in OSPAR and 8 out of 9 countries in HELCOM. This can facilitate the development of common actions within each of these regions, so that coordinated monitoring programmes can improve cost-effectiveness and enable larger-scale assessments [26]. In contrast, the Mediterranean Sea and the Black Sea include a lower proportion of MSFD MS within the RSCs contracting parties: 8 out of 21 countries in UNEP/MAP and 2 out of 6 countries in BSC. Under these circumstances, where a large proportion of countries are not obliged to implement MSFD approaches, coordination in the Southern European seas seems complex and may require extra effort/initiatives. Moreover, three of these regions (Mediterranean Sea, Baltic Sea and Black Sea) are semi-enclosed sea basins, increasing their vulnerability to environmental pollution such as marine litter.

Table 2 MSFD Criteria and RSCs indicators for marine litter monitoring on the coastline/beach (grey lines: monitoring indicators not considered)

Macro-litter on coastline/beach

Institution	Criteria/Indicator	Litter size	Units	Assessment approach	Guidelines	Other References
EU MSFD [15]	Primary Criteria - D10C1	Meso- (5-25mm) and macro- (> 25mm)	Number of items per 100 metre of coastline	Thresholds (under development)	[22], [25]	
OSPAR	Common Indicator - Beach litter	All visible litter on the beach surface	Number of items on standard 100m stretches of coastline	Trends	[27], [30]	
HELCOM	Litter Sub-programme: Macro-litter characteristics and abundance/volume	> 5mm	Number of litter items per 100 m beach segment	Trends (EU Thresholds under development)	[36], [38]	[27], [37], [47]
UNEP/MAP	Common Indicator 22 - Trends in the amount of litter washed ashore and/or deposited on coastlines, i.e. Beach Litter	> 5mm (possible review to > 25mm in the future)	Items/100m transect and items/m^2	Trends	[42], [43]	[25], [37], [48]
BSC	n.a.	n.a.	n.a.	n.a.	n.a.	

Micro-litter on coastline/beach

Institution	Criteria/Indicator	Litter size	Units	Assessment approach	Guidelines	Other References
EU MSFD [15]	Primary Criteria - D10C2	Micro- (< 5mm)	Number of items and weight in grams (g) per kilogram (dry weight) (kg) of sediment	Thresholds (under development)	[22], [25]	
OSPAR	n.a.	n.a.	n.a.	n.a.	n.a.	
HELCOM	Litter Sub-programme: Micro-litter characteristics and abundance/volume	n.a.	n.a.	n.a.	n.a.	[25]
UNEP/MAP	n.a.	n.a.	n.a.	n.a.	n.a.	
BSC	n.a.	n.a.	n.a.	n.a.	n.a.	

n.a. (not available)

OSPAR is delivering a series of advice and coordination and reporting support documents [27]. In terms of monitoring, OSPAR provided the Joint Assessment & Monitoring Programme (JAMP) 2014–2023 [26] and a Coordinated Environmental Monitoring Programme (CEMP) (adopted from 2016 for the North-East Atlantic region), with reference not only to the OSPAR Strategy but also to the MSFD [28]. The OSPAR coordinated monitoring considers beach litter and litter on the seabed as common indicators; an additional common indicator for the Greater North Sea (OSPAR Region II) is the fulmar (*Fulmarus glacialis)* litter ingestion (impact and floating litter) [29]. Moreover, the OSPAR JAMP foresees implementing monitoring programmes based on indicators for microplastics in sediments and impacts (e.g. ingestion and entanglement) on turtles [26]. OSPAR has available CEMP monitoring guidelines for beach litter [30], seabed litter [31] and plastic particles in stomachs of fulmars in the North Sea area [32].

In the Baltic Sea, a HELCOM Group for the Implementation of the Ecosystem-Based Approach (HELCOM GEAR) was established in 2012, which includes among it tasks facilitating regional coordination in the implementation of the Baltic Sea Action Plan (BSAP) and the MSFD for EU MS in the region [33], while Russia

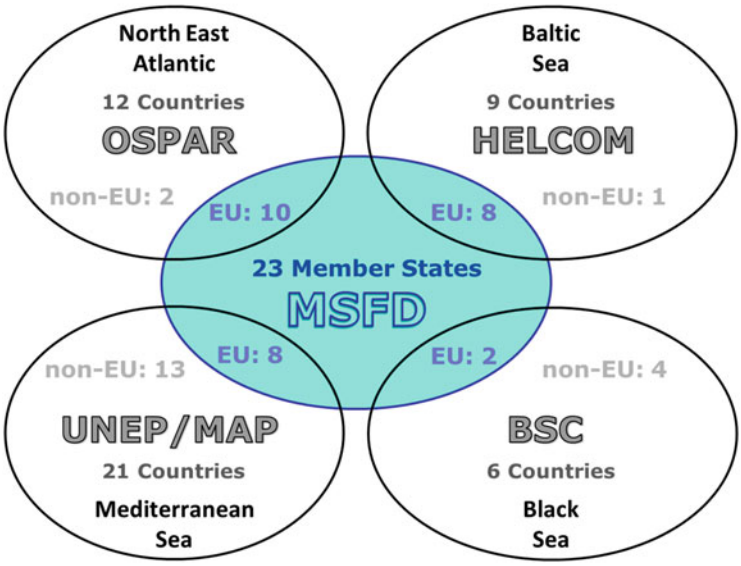

Fig. 2 Number of EU (23) and non-EU (19) countries per European sea basin, considering total number of coastal countries (41) involved in the MSFD and/or their corresponding Regional Sea Conventions: OSPAR, HELCOM, UNEP/MAP and BSC (Note that the sum of countries per basin exceeds the total number 41 because some countries are contracting parties in two RSCs: Spain, France, Denmark, Germany, Sweden, Russian Federation and Turkey)

follows the policy under the Maritime Doctrine of the Russian Federation. Correspondingly, the HELCOM Monitoring and Assessment Strategy [34] considers commitments under the BSAP and the MSFD, including a thematic monitoring programme for amount and composition of marine litter. The HELCOM Monitoring Manual acknowledges two subprogrammes: monitoring of micro-litter particles in water column, beach and bottom sediment (depending on the national programmes) and monitoring of macro-litter on the beach, in the water surface, on the seafloor and in biota [35]. However, only a guideline for monitoring beach litter is available [36], seeking harmonization with OSPAR [27], UNEP/IOC [37] and MSFD TG ML [25] where possible [38].

UNEP/MAP also opted for the implementation of an Ecosystem Approach (EcAp) in order to achieve the Good Environmental Status (GES) of the Mediterranean Sea and Coast [39], adopting a road map in 2012 [40]. In 2016, UNEP/MAP adopted a novel Integrated Monitoring and Assessment Programme of the Mediterranean Sea (IMAP), including a list of indicators for their EcAp Ecological Objectives (EO) [41]. In EO10 (marine litter), monitoring included two common indicators, (22) trends in the amount of litter washed ashore and/or deposited on coastlines (beach litter) and (23) trends in the amount of litter in the water column, including microplastics, and on the seafloor, and one candidate indicator: (24) trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds and marine turtles. UNEP/MAP also offers

monitoring and assessment methodological guidance for EO10 regarding (22) beach, (23A) seafloor and (23B) floating litter, and (24) litter in biota [42, 43], based on the UNEP Operational Guidelines for Comprehensive Beach Litter Assessment [37] and the MSFD Guidance on Monitoring of Marine Litter [25].

The Black Sea Integrated Monitoring and Assessment Program (BSIMAP) 2017–2022 has incorporated marine litter under its Ecological Quality Objective 4a (EcoQO 4a) (Reduce pollutants originating from land based sources), using the title of the MSFD Descriptor 10: Properties and quantities of marine litter do not cause harm to the coastal and marine environment. It considers as common indicators: trends in the amount of litter in the water column including microplastics, floating litter and litter deposited on the seafloor and trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds and fish. Most recent communication with the BSC Secretariat (June, 2019) indicated that Guidelines on Marine Litter in the Black Sea have been drafted, based on JRC experience (e.g. MSFD guidance on monitoring by Galgani et al. [25]) and in agreement with UNEP/MAP, but not yet formally adopted, and therefore not obligatory to report on marine litter at the moment.

Moreover, Turkey (EU candidate country) is involved in the implementation of environmental assessment approaches aligned to EC Directives, including MSFD-related projects such as 'Capacity building on Marine Strategy Framework Directive in Turkey' (2015–2017), aimed at developing institutional and technical capacity for the transposition and implementation of the MSFD [44]. Therefore, coherence and harmonization with MSFD and RSCs is expected in the Turkish monitoring programmes for both Mediterranean Sea and Black Sea regions. Additionally, the EU-funded project EMBLAS-Plus (Environmental Monitoring in the Black Sea) [45] promotes activities to facilitate joint monitoring of marine litter, aligned with the MSFD and the BSIMAP, in the non-EU countries of the Black Sea: Ukraine, Russia and Georgia. Coordination between EU and non-EU countries for harmonized monitoring and assessment approaches is important in the shared basins.

4 Marine Litter Monitoring Elements in the European Sea Basins

Tables 2, 3, 4 and 5 present a further description of the existing monitoring approaches by reviewing the marine litter monitoring elements (criteria and indicators) considered in the MSFD and the RSCs. In general, the litter size categories are harmonized to differentiate micro-litter <5 mm from other fractions (meso- and macro-). The limit between meso-litter (5–25 mm) and macro-litter (>25 mm) is not explicitly mentioned, not even in the COM DEC, where criteria refer only to 'micro-litter (particles <5 mm)' and 'litter (excluding micro-litter)'. The differentiation between meso- and macro-litter is based on the technical necessity to allow for

Table 3 MSFD Criteria and RSCs indicators for marine litter monitoring in the surface layer of the water column (grey lines: monitoring indicators not considered)

Macro-litter in the surface layer of the water column

Institution	Criteria/Indicator	Litter size	Units	Assessment approach	Guidelines	Other References
EU MSFD [15]	Primary Criteria - D10C1	Meso- (5-25mm) and macro- (> 25mm)	Number of items per square kilometre	Thresholds (under development)	[22], [25]	
OSPAR	n.a.	n.a.	n.a.	n.a.	n.a.	
HELCOM	Litter Sub-programme: Macro-litter characteristics and abundance/volume	n.a.	n.a.	n.a.	n.a.	[37]
UNEP/MAP	Common Indicator 23 - Trends in the amount of litter in the water column including microplastics and on the seafloor	Macro- (> 25mm)	Items per square kilometre	Trends	[42], [43]	[49]
BSC	Common indicator - Trends in the amount of litter in the water column incl. microplastics, floating litter and deposited on the seafloor	n.a.	n.a.	Trends	n.a.	

Micro-litter in the surface layer of the water column

Institution	Criteria/Indicator	Litter size	Units	Assessment approach	Guidelines	Other References
EU MSFD [15]	Primary Criteria - D10C2	Micro- (< 5mm)	Number of items and weight in grams (g) per square metre	Thresholds (under development)	[22], [25]	
OSPAR	Additional Common Indicator - Fulmar litter ingestion in the North Sea area (impact and floating litter)	Mostly micro- (< 5mm) and meso- (5-25 mm); lower limit 1mm	Number and weight in grams of plastic particles in stomachs of *Fulmarus glacialis*	EcoQO performance; Trends	[32]	
HELCOM	Litter Sub-programme: Micro-litter characteristics and abundance/volume	n.a.	n.a.	n.a.	n.a.	[25]
UNEP/MAP	Common Indicator 23 - Trends in the amount of litter in the water column including microplastics and on the seafloor	Micro- (< 5mm)	Items per square kilometre	Trends	[42], [43]	[25], [37]
BSC	Common indicator - Trends in the amount of litter in the water column incl. microplastics, floating litter and deposited on the seafloor	n.a.	n.a.	Trends	n.a.	

n.a. (not available)

human observation on larger surfaces where 25 mm have been agreed as a lower size limit. The MSFD Guidance on Marine Litter Monitoring had previously appointed the methodological gaps existing in the monitoring of meso-litter, the latter being a size range relevant for biota ingestion issues [25]. It is important to define the size ranges included in the assessment as the monitoring methodologies must be designed in order to collect representative data and facilitate further comparable assessments.

The monitoring of macro-litter on the coastline/beach is the best described and established monitoring element, including availability of monitoring guidelines for the MSFD and three of the RSCs (OSPAR, HELCOM and UNEP/MAP) (Table 2). Conversely, even though it was investigated in the 'Marine Litter in the Black Sea

Table 4 MSFD Criteria and RSCs indicators for marine litter monitoring on the seabed (grey lines: monitoring indicators not considered)

Macro-litter on the seabed

Institution	Criteria/Indicator	Litter size	Units	Assessment approach	Guidelines	Other References
EU MSFD [15]	Primary Criteria - D10C1	Meso- (5-25mm) and macro- (> 25mm)	Number of items per square kilometre	Thresholds (under development)	[22], [25]	
OSPAR	Common Indicator - Litter on the seabed	> 50x50mm (area)	Number of items per square kilometre	Trends	[31]	
HELCOM	Litter Sub-programme: Macro-litter characteristics and abundance/volume	n.a.	n.a.	n.a.	n.a.	[37]
UNEP/MAP	Common Indicator 23 - Trends in the amount of litter in the water column including microplastics and on the seafloor	Macro- (> 25mm)	items/ha or items/km^2	Trends	[42], [43]	[25], [37], [53], [54]
BSC	Trends in the amount of litter in the water column incl. microplastics, floating litter and deposited on the seafloor	n.a.	n.a.	Trends	n.a.	

Micro-litter on the seabed

Institution	Criteria/Indicator	Litter size	Units	Assessment approach	Guidelines	Other References
EU MSFD [15]	Primary Criteria - D10C2	Micro- (< 5mm)	Number of items and weight in grams (g) per kilogram (dry weight) (kg) of sediment	Thresholds (under development)	[22], [25]	
OSPAR	n.a.	n.a.	n.a.	n.a.	n.a.	
HELCOM	Litter Sub-programme: Micro-litter characteristics and abundance/volume	n.a.	n.a.	n.a.	n.a.	[25]
UNEP/MAP	n.a.	n.a.	n.a.	n.a.	n.a.	
BSC	Common indicator - Trends in the amount of litter in the water column incl. microplastics, floating litter and deposited on the seafloor	n.a.	n.a.	Trends	n.a.	

n.a. (not available)

Region' report from 2009 [46], the BSC does not mention beach litter monitoring in their BSIMAP 2017–2022. Unlike for macro-litter, the monitoring of micro-litter on the coastline/beach has barely been developed (Table 2); only the MSFD is providing guidance (mostly recommendations included in [25]), and HELCOM includes it under their micro-litter subprogramme, but no specifications have been given.

Floating macro-litter is covered as a monitoring element by all the institutions (Table 3). Moreover, all MSFD and the four RSCs take into account the monitoring of floating micro-litter, but guidance is only available for MSFD, OSPAR and UNEP/MAP. Different from the rest of the approaches, OSPAR relies on the fulmar litter ingestion indicator as a proxy for floating litter monitoring, considering micro-litter in the range of 1–5 mm and meso-litter 5–25 mm. Fulmars are pelagic seabirds that forage exclusively at sea, diving in the first meters of the surface layer and regularly ingesting marine litter, which is being used as an indicator for 'impact on biota' and is also considered as a proxy for floating litter abundance [32]. Results

Table 5 MSFD Criteria and RSCs indicators for marine litter monitoring in biota (ingestion of and entanglement in) (grey lines: monitoring indicators not considered)

Biota litter ingestion

Institution	Criteria/Indicator	Litter size	Units	Assessment approach	Guidelines	Other References
EU MSFD ([15]	Secondary Criteria - D10C3	Micro- (< 5mm), meso- (5-25mm) and macro- (> 25mm)	Grams of litter/micro-litter and number of items per individual (for each species and in relation to individuals' size)	Thresholds (under development)	[22], [25]	
OSPAR	Additional Common Indicator - Fulmar litter ingestion in the North Sea area (impact and floating litter)	Mostly micro- (< 5mm) and meso- (5-25 mm); lower limit 1mm	Number and weight in grams of plastic particles in stomachs of *Fulmarus glacialis*	EcoQO performance; Trends	[32]	
HELCOM	Litter Sub-programme: Macro-litter characteristics and abundance/volume	n.a.	n.a.	n.a.	n.a.	
UNEP/MAP	Candidate Common Indicator 24 - Trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds and marine turtles	> 1mm	Number of items and weight in grams per individual (stomach content of marine birds and/or turtles)	Trends	[42], [43]	[25], [32], [37]
BSC	Common indicator - Trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds, fish	n.a.	n.a.	Trends	n.a.	

Biota litter entanglement and other adverse effects

Institution	Criteria/Indicator	Litter size	Units	Assessment approach	Guidelines	Other References
EU MSFD [15]	Secondary Criteria - D10C4	n.a.	Number of individuals with lethal or sub-lethal impacts per species	Thresholds (under development)	[22], [25]	
OSPAR	n.a.	n.a.	n.a.	n.a.	n.a.	
HELCOM	Litter Sub-programme: Macro-litter characteristics and abundance/volume	n.a.	n.a.	n.a.	n.a.	
UNEP/MAP	Candidate Common Indicator 24 - Trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds and marine turtles	n.a.	n.a.	Trends	n.a.	[25], [37]
BSC	Common indicator - Trends in the amount of litter ingested by or entangling marine organisms focusing on selected mammals, marine birds, fish	n.a.	n.a.	Trends	n.a.	

n.a. (not available)

obtained from the monitoring of fulmar litter ingestion are not comparable with the actual monitoring of litter floating at sea (e.g. number of items per square kilometre).

Macro-litter on the seabed is considered by all institutions (Table 4), and monitoring guidelines are provided for MSFD, OSPAR and UNEP/MAP. For HELCOM and BSC, details need to be defined. On a large scale, an important asset to provide

consistent and harmonized collection of trawling data is the collaboration/cooperation of the RSCs with international fish-trawl surveys [25], such as the International Bottom Trawl Survey (IBTS) in the North-East Atlantic region [50], the Baltic International Trawl Surveys (BITS) [51] and the International Bottom Trawl Survey in the Mediterranean (MEDITS) [52]. Different trawling gear though provides data that are not comparable. The coordinated monitoring of seabed litter in areas not subject to trawling is currently not established. Scientific surveys, mainly with remotely operated vehicle (ROV), provide initial information in areas with morphology that does not permit trawling. Regarding micro-litter on the seabed, this monitoring element is currently considered by MSFD, HELCOM and BSC (Table 4). Meanwhile, OSPAR plans to develop an indicator for the monitoring of microplastics in sediments [26].

Monitoring the ingestion of litter by biota has been considered by all institutions, providing guidelines for MSFD, OSPAR and UNEP/MAP, but no specifications for HELCOM and BSC (Table 5). In the case of biota entanglement with litter, although this monitoring element is also considered by all institutions, no guidelines or further details have been developed by any RSC (Table 5). Research efforts are being put in place in order to fill knowledge gaps through projects such as INDICIT I and INDICIT II for the 'Implementation Of Indicators Of Marine Litter On Sea Turtles And Biota In Regional Sea Conventions And Marine Strategy Framework Directive Areas' [55].

An overview of the existing marine litter monitoring elements shows a high degree of common criteria/indicators as a starting point for future comparable assessments between MSFD and the RSCs countries. Nevertheless, there are still significant differences in the maturity of approaches, subject frequently to gaps, or lack of harmonization. Even in the most matured elements, such as macro-litter on the coastline/beach or macro-litter on the seabed, some RSCs have not yet defined monitoring guidelines, and the MSFD is considering updates to the existing ones. The implementation of marine litter monitoring programmes is under further development, and rapidly evolving, supported by research activities and regulations updates.

5 Summary and Conclusions

The European seas present a complex scenario for environmental management: a large number of EU and non-EU countries sharing semi-enclosed sea basins and overlapping transnational frameworks for the protection of the marine environment. Cooperation initiatives have been launched in order to overcome lack of harmonization and the risk of duplicating efforts in the monitoring and assessment of marine litter pollution. Some of these initiatives pursue the alignment of monitoring approaches to ensure availability of common monitoring elements at the European scale, which further leads to coherent and comparable assessments. It is important to note that the MSFD TG ML is a key player in this process, bringing together

international scientific experts, and representatives from the four RSCs, for coordination purposes. The MSFD TG ML publications [24] have provided monitoring approaches and methodological standards for many MS that lacked knowledge and data on the issue of marine litter, during the implementation of the MSFD. On many occasions, the *Guidance on Monitoring of Marine Litter in European Seas* [25] has been an essential document in the development and alignment of monitoring approaches for the RSCs.

The review of the monitoring elements currently used reveals gaps in coverage and maturity of approaches. Road maps and actions are implemented in order to bridge those gaps based on cooperation agreements.

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Plastics in the Austrian Stretch of the Danube River: From Environmental Data to Action Plans at the Local, National, and International Level

Philipp Hohenblum and Nina Maier

Contents

Abstract The issue of plastics in the aquatic environment emerged from discussions in the marine sphere. Approximately 80% of marine litter has land-based sources, with rivers suspected to be major pathways towards the marine environment. Lately, several studies from numerous rivers legitimate this concern. Recently, also a good share of studies have been initiated or have been conducted by public authorities in order to evaluate the burden of the aquatic environment with (micro) plastics with a view to conclude concrete steps for reducing their sources.

This article deals with a case study on the presence of plastics in the Austrian stretch of the Danube River. The results of the study led to several activities at the national and international level. In particular, by addressing the topic at the European level by Austria, the Network of European Environmental Agencies decided to establish an (voluntary) Interest Group Plastics to share experiences and knowledge in the member states and to address the issue of plastics in the environment towards the European Commission. Major contribution of the Interest Group Plastics was an input to the EU Plastics Strategy, which has been endorsed by 15 member states.

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1 Introduction

Due to their stability and durability, plastics endure over long periods in the environment without being significantly degraded. In contrast to chemical or biological contaminants, for which we have to trust analytical investigations to detect their presence, plastics are normally well visible. According to our experience with plastics in daily life, people can easily distinguish larger plastic particles from natural environmental compartments and identify them as foreign material. This makes plastic a tangible environmental problem and is probably one of the reasons why the topic receives high attention in the media. This increased awareness, especially of the subject of marine litter, led to somehow emotional discussions and partially to condemning plastics altogether. There is a need to balance the discussion on plastics, to understand the pathways and fate of plastic waste in the environment, and to derive measures or to evaluate their effectiveness. Therefore, solid data is needed.

Oceans are sinks for aquatic and consequentially land-based contaminations. Reports from the 1990s of the twentieth century about the Pacific Ocean and later on practically all the other oceans revealed remarkable plastic concentrations, sometimes not quite correctly referred to as plastic patches or plastic gyres. Rivers are suspected to be major pathways, but still, there is only little data on the presence of plastics in rivers. This is a significant knowledge gap, as 80% of the oceans' plastic burden comes from land-based sources [1–3].

In 2014, the Austrian Federal Ministry for Agriculture, Forestry, Environment and Water Management in collaboration with the provincial governments of Lower Austria, Upper Austria, and Vienna initiated a study on plastics in the Danube River, Austria's major river. The study has been designed and led by the Environment Agency Austria in cooperation with the University of Natural Resources and Life Sciences and via donau, the Austrian waterways company. The main aim of the study was to elaborate sound data of plastics transported by the river and to suggest measures. At the time of conceptualizing the study, numerous studies on the marine environment were available, but there was only little knowledge on freshwater bodies [4, 5]. In order to seek and explore unpublished knowledge, the authors consulted the "Network of the Heads of Environment Protection Agencies" (EPA Network; see below) and asked for experiences and general awareness of recent research on plastics in freshwater environments of other agencies. However, most responses referred to ongoing studies in the marine environment and considerable knowledge gaps on plastics in freshwater systems.

2 The Role of Public Authorities

In order to investigate the burden of plastics in the Danube River, a methodology for sampling plastic particles has been elaborated, powerful enough to withstand the river's forces and to allow for sampling sufficient volumes. This was necessary in order to hold back a reasonable number of plastic particles as a prerequisite to analyze and substantiate the transport of plastics in the river [6]. In addition, several ecological, technical, and economical aspects of plastics have been investigated. In the end, all the gathered knowledge led into suggestions for measures to reduce the amount of plastics in the river. Consequently, the Austrian Federal Ministry for Agriculture, Forestry, Environment and Water Management issued a 10-point action plan to combat plastic pollution in the Danube River [7]. Among other points, the plan comprised the organization of an international stakeholder conference, the organization of the 60th Eurovision Song Contest in Vienna as a green event, and signing of a voluntary agreement with the industry to avoid the emission of pellets. It described actions at the local, national, and EU level.

The voluntary agreement on pellet loss [8] comprises ten measures by which the signing parties commit to reduce their pellet emissions to less than 1 kg per day. The measures are easily applicable and are mostly already part of day-to-day business. They aim at raising the awareness to follow and control the procedures inside the companies. According to the partners of the agreement, the reduction goal could be achieved within 1 year. The suggested measures are:

1. Providing collection baskets for pellets at loading sites
2. Strategic placement of bins for disposal on sites
3. Regular control of all gullies for correct retention sieves
4. Thorough sealing of containers before shipping
5. Control of containers for full clearance
6. Ensuring that roofs of silo wagons are free of pellets after loading
7. Installation of exhaust systems, where appropriate
8. Thorough disposal of loose pellets
9. Training of personnel
10. Informing logistic partners on measures to limit pellet loss

In order to address the international community and the European Commission, the Ministry organized in collaboration with the Environment Agency Austria and the EPA Network a Stakeholder Conference in Brussels "Elimination Plastic and Microplastic Pollution – an Urgent Need" [9]. The conference aimed at bringing together relevant stakeholders and at discussing actions needed to tackle the issue of plastics in the environment at the European level. One of the results of the conference was the establishment of an Interest Group Plastics (IG Plastics), chaired by the German Environment Agency.

The Network of Heads of Environment Agencies (EPA Network) is an informal group bringing together the heads and directors of environment protection agencies

(EPAs) and similar bodies across Europe. The network exchanges views and experiences on issues of common interest to organizations involved in the practical day-to-day implementation of environmental policy. It is organized in nine working groups (called interest groups). They consist of experts from different agencies, meet regularly, and give input to the network on specific topics.

The Interest Group Plastics consists of EPA experts working in various environmental fields. The group has an interdisciplinary approach building on the experts' day-to-day practical experience with regulative measures pertaining to plastics. The overall focus lies on identifying relevant policy fields and on addressing the most efficient measures.

To support the European Commission in elaborating the EU Plastics Strategy as a part of the EU Action Plan for a Circular Economy, the interest group compiled a document with consolidated views, positions, and recommendations on the EU roadmap prior to the publication of the EU Plastics Strategy. The document "Recommendations towards the EU Plastics Strategy" was endorsed in April 2017 by 14 EPAs and was submitted to the Directorate-General for Environment [10]. The paper consists of seven main points, which from the perspective of IG Plastics need to be reflected in an EU strategy to reduce or prevent unwanted plastic entries. The main topics addressed in the paper are:

- Prevention of plastic waste
- Addressing individual targets for each country
- The importance of green public procurement
- Standardization needed to regulate plastic material
- Measures to increase recycling
- The role of deposit schemes
- Critical assessment of bioplastics

Views and positions of the IG Plastics on these topics were underpinned by a number of examples and recommendations for measures. In addition, the IG Plastics encouraged DG ENV to regularly update and adapt the strategy. For this reason, the IG Plastics proposed to set up a monitoring mechanism composed of stakeholders of the entire material value chain to show the effectiveness of the implementation of the strategy. The IG Plastics also highlighted that marine litter is recognized as one of the major environmental problems and therefore intergovernmental structures should address it. There are regional action plans in place (MEDPOL, OSPAR, HELCOM, Black Sea Convention) which are backed up by national programs of measures according to the EU Marine Strategy Framework Directive, and the G7 and G20 agreed on an action plan to reduce marine litter at a global level. After submission to the European Commission, the recommendations of the IG Plastics were discussed at a stakeholder conference in Brussels in June 2017. The results were presented in a conference report.

The global perspective and challenge to fight marine litter was also addressed in a second stakeholder conference as a follow-up of the 2015 event [11]. The conference was organized under the auspices of the Austrian Council Presidency (represented

by the Ministry for Sustainability and Tourism and the Environment Agency Austria) in November 2018 in collaboration with the EPA Network (IG Plastics) and the International Union for Conservation of Nature (IUCN). The conference focused on the current situation and activities ongoing in the EU but also embraced the global level by displaying examples of good practice and initiatives to transfer knowledge outside the EU. The overall question was how different stakeholders can best support the political process and which initiatives and actions complement the way forward by transferring best practices and knowledge beyond the EU. Participants concluded that a suite of instruments is needed to tackle the problem of marine litter. Both legislation and voluntary schemes by industry and an open dialogue between all stakeholders need to be maintained. In terms of research, more collaboration of EC directorates with member states' research bodies and authorities was specifically mentioned. Also, existing platforms like the EPA Network's Interest Group help forming opinions on emerging issues like textiles or tire wear and help liaise between the different stakeholders.

3 Conclusions

The Austrian example demonstrates the role of public entities and their collaboration (ministry, agency, provincial governments) and responsibility in elaborating environmental data for the thorough assessment of situations or for the evaluation of the effectiveness of measures taken. As an example, the 10-point action plan to combat plastic pollution, which has been issued by the Austrian Minister for the Environment, demonstrates actions at the local, national, and EU level. In particular, the voluntary agreement with industry highlights actions beyond legal obligations, which have been triggered by a public entity. The transfer of national experiences to the international level, by, e.g., bringing together stakeholders to conferences, has been proven successful. The best example is the establishment of the Interest Group Plastics of the EPA Network, which brings together national experiences and positions in order to substantiate the EU Plastics Strategy.

Plastics have numerous interfaces with the environment along their value chain, from production, product design, material conversion, use phase, and at the end of life as recycling material or waste. Tackling environmental plastics (and especially marine litter) needs a strong commitment of all stakeholders, as has been concluded in the second Stakeholder Conference "Eliminating Plastic and Microplastic Pollution – an Urgent Need." Moreover, participants largely agreed that both legal and voluntary measures were needed to combat the problem at the regional, national, and global level.

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Plastics in Freshwater: A New Challenge for the International Commission for the Protection of the Rhine (ICPR)?

Tabea Stötter and Anne Schulte-Wülwer-Leidig

Contents

Abstract In the International Commission for the Protection of the Rhine (ICPR), the nine states in the river basin and the European Commission cooperate in order to harmonise the many interests of use and protection in the Rhine area. Plastics in the Rhine is a new topic for the commission, and there is a regular information exchange since 2013 about research projects, workshops, conferences and other initiatives in the countries in the Rhine catchment. The countries are already active, and there are new developments and results on short intervals. The available studies so far show variable concentrations of plastics, and it is difficult to rely on absolute numbers. Nevertheless, the studies show that plastics are of ubiquitous occurrence. Based on the idea of prevention, it is necessary to reduce inputs of plastics into the environment, including rivers. Possible actions for the ICPR are already discussed but postponed until more information and suitable techniques are available. Besides, the information exchange in the ICPR, between the countries in the Rhine catchment and with the intergovernmental organisations (IGOs) and non-governmental organisations (NGOs) in the ICPR, will continue.

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1 Introduction

In the International Commission for the Protection of the Rhine (ICPR), the nine states in the river basin (see Fig. 1) and the European Commission cooperate in order to harmonise the many interests of use and protection in the Rhine area. The Convention on the Protection of the Rhine is the basis for international cooperation for the protection of the Rhine within the ICPR. The European directives (Water Framework Directive (WFD), Floods Directive (FD)) and the corresponding ICPR programmes provide the basis of the work today. Besides, there is a working programme, which is updated and adopted on a regular basis.

The latest River Basin Management Plan of the Rhine [1], published in December 2015, showed that the Rhine is still facing challenges and has not reached the goal of a good status or potential (according to EU regulations) yet. Remaining issues are, for example, the increase of habitat diversity and river continuity for fish. The chemical challenges include especially ubiquitous substances. Because of their persistence and widespread occurrence, there are few measures for reducing the pollution with these substances in the short or medium term.

An additional upcoming topic in the Rhine catchment is waste in surface water and the sea. The Marine Strategy Framework Directive (MSFD) obliges the EU member states to take measures to achieve the good environmental status in the marine waters by 2020 and/or to maintain this status. One descriptor of the MSFD is that “Properties and quantities of marine litter do not cause harm to the coastal and marine environment”. There are three issues that require an integration of the MSFD and WFD, which are biodiversity/diadromous fish species (migratory fish and their migration between inland waters and salt water), nutrients and pollutants and waste. The first two issues are treated in different ICPR working groups since many years. Waste, on the other hand, is a new topic for the ICPR. But, as one input pathway into the marine environment happens via rivers, it is also a relevant topic for river commissions.

Waste found in the environment consists of a large extent of plastics, as it is a widely used material [2] and has most often a very long lifetime. In collection initiatives in the Netherlands, for example, seven out of ten most found waste types along the river shore were plastics [3].

Plastics are synthetic polymers out of many different materials, with different sizes and shapes. Although there are no universal definitions, one can generally distinguish macro- and microplastics. Microplastics again can be divided into primary and secondary plastics. The first group enters the environment already in the microscopic size, either through intended production (e.g. used in cosmetics and personal care products) or formation during usage (e.g. synthetic fibres). And the latter is formed in the environment through degradation of macroplastics.

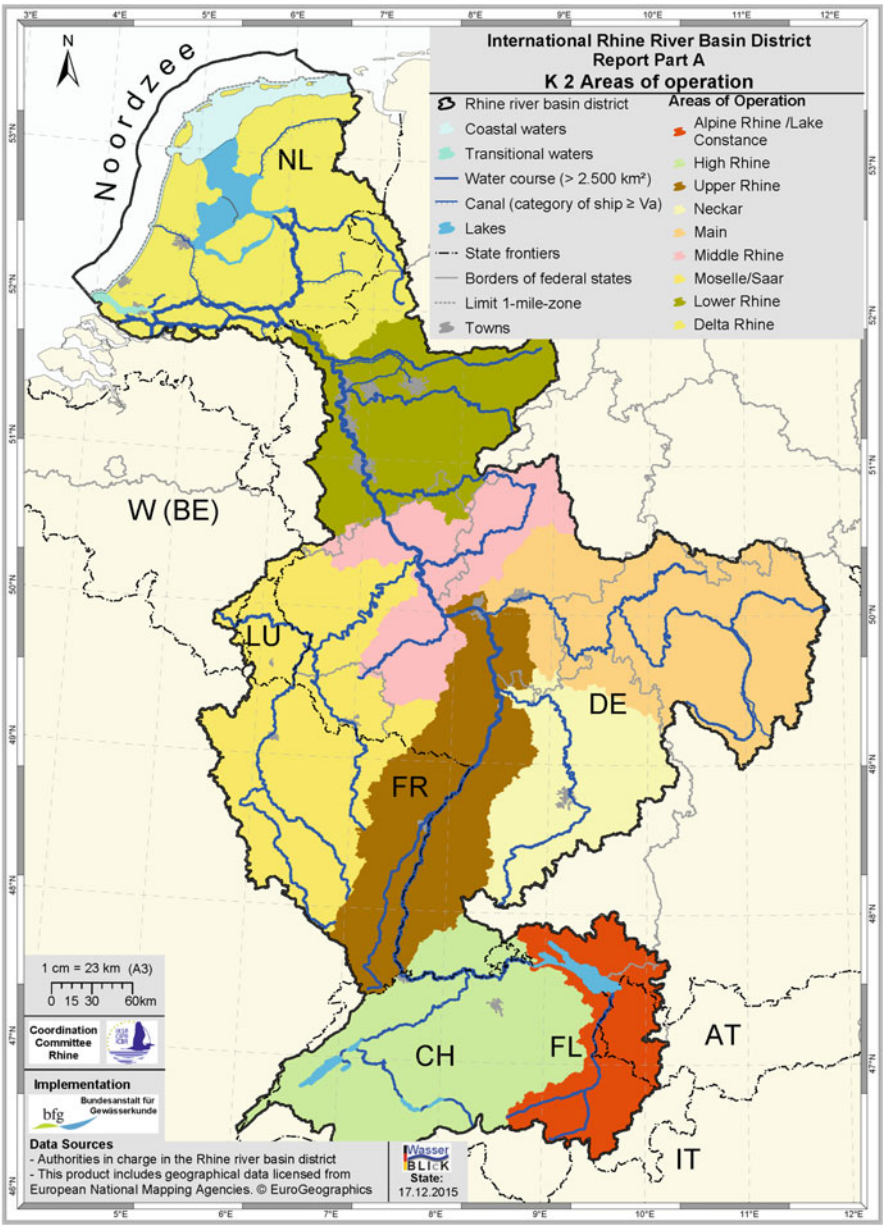

Fig. 1 International river basin district of the Rhine (River basin management plan 2015 [1])

Possible sources of plastics into the river are, e.g. waste coming from public areas, agriculture, industry, waste water treatment plants, discharge of untreated rain water, shipping and leisure activities.

Although plastics in the environment and especially in waters is a widely discussed topic, nowadays there are still many unknowns. The load situation is not clear yet, and also when it comes to methods, e.g. for sampling or analysis, there are many open questions and a need for harmonisation.

Nevertheless, (macro- and micro-) plastics are contaminants in the aquatic ecosystem, which can be potentially harmful. Inputs of plastics should be reduced as much as possible or completely stopped.

The ICPR is discussing plastics since 2013, mostly due to the MSFD.

2 The International Commission for the Protection of the Rhine (ICPR)

The Rhine is an important river in central Europe. It has a length of 1,233 km and is Europe's most important navigation route, while it is navigable on 825 km. In the catchment area, there are 60 million inhabitants, and 30 million people rely on the Rhine as a basis for their drinking water supply.

The ICPR was founded already in 1950 and is an intergovernmental organisation. The cooperation of the nine states in the river basin and the European Commission is based on legally binding conventions and/or since 2000 on EU directives. Decisions are made by consensus, and defined measures are no obligations but recommendations. The conference of Rhine Ministers takes decisions related to important political questions and provides the basis for coherent, complementary programmes of measures. The ministerial meeting is taking place around every 6 years.

The secretariat and its international staff located in Koblenz (Germany) support this work. The secretariat is in charge of organising and preparing the contents of meetings as well as of linguistic support in the working languages German, French and Dutch. At the same time, the secretariat is in charge of public relations and serves as a contact for experts and interested citizens.

The three main work topics of the ICPR are flood and low water, water quality/emissions and ecology (see Fig. 2). Each of these working groups has its expert groups, dealing, for example, with the monitoring. On top there are strategic groups, which, for example, set the working programme and publish reports.

Since 1999 organisations can get an observer status. They attend meetings of working and expert groups and at the plenary assembly, and they meet the ICPR president once a year. At the moment there are 8 intergovernmental organisations (IGOs), like the Central Commission for the Navigation of the Rhine, and 20 non-governmental organisations (NGOs) with an observer status. The NGOs with the observer status have different backgrounds. There are several flood and nature protection organisations but also the chemical industry, drinking water industry and fishery organisations.

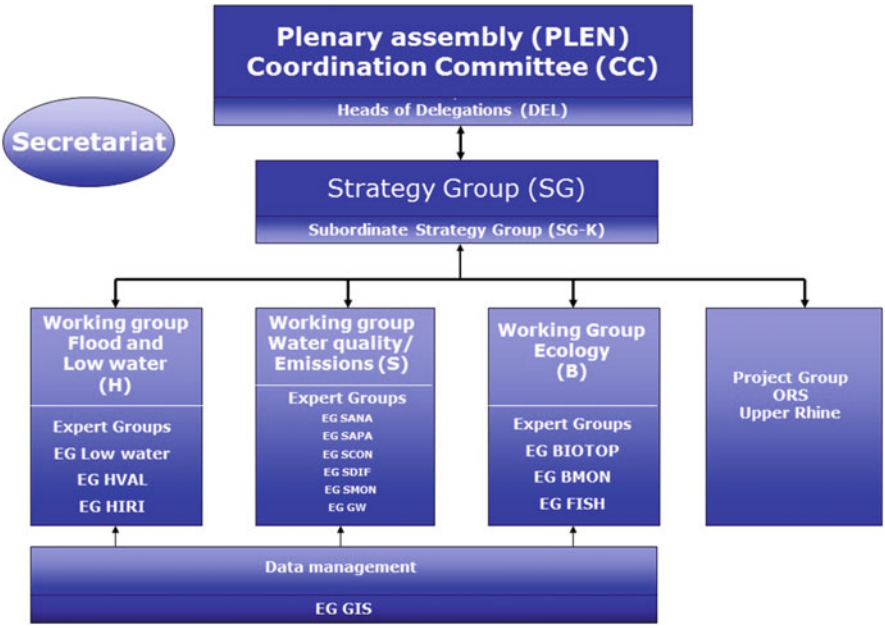

Fig. 2 Organisation structure of the International Commission for the Protection of the Rhine (ICPR) [4]

3 Current Knowledge of Contamination with Plastics in the Rhine

The ICPR is not monitoring plastics so far. Therefore, only different scientific studies are available, which can give a first insight. Because of the limited monitoring time, it is often more a snapshot than a broad overview. These studies are a first approach to this extensive topic.

In 2013 some first studies about plastics, including statements about the Rhine, were published. For example, Deltares (2013) [5] estimated for macroplastics that all rivers pouring into the North Sea contribute 15,000 m^3 per year, with the Rhine adding one third of it. This estimation was based on different assumptions.

Brandsma et al. [6] performed measurements of microplastics in suspended particulate matter at two locations in the Rhine. These were Lobith and Bimmen, both located at the German-Dutch border. The highest concentrations, based on two measurements, were found at Lobith with 4,900 $\pm$ 540 particles/kg dry weight. In Bimmen 1,700 $\pm$ 390 particles/kg dry weight were found.

In 2015 several studies about plastics were published including the Rhine. Mani et al. [7] analysed microplastics in surface waters of the Rhine at 11 places. Microplastics were found in all samples, on average more than 890,000 particles per km^2 (surface water sampled with Manta net). The highest concentrations found were located in the Ruhr metropole region with 3.9 million particles per km^2. The

concentrations were diverse along and across the river, reflecting various sources and sinks.

Urgert [8] analysed the abundance and composition of microplastics in the Dutch parts of the European rivers Meuse and Rhine, in 80 cm and 3 m below the water surface. Particles were identified visually. In the Rhine the average concentration of particles (size 0.125–5 mm) were 0.56 mg or 56 microplastics per m^3 (visually counted and separated under a stereo microscope).

Van der Wal et al. [9] analysed samples from the Rhine, Dalålven, Po and Danube. The focus was to estimate the plastic input of these rivers into the sea. Therefore, the sampling locations were chosen on a dominant branch in a river delta, within approximately 50 km of the mouth, and downstream of the last major influences, like urban areas. The Rhine was sampled in Rotterdam and they also took samples in the North Sea. Plastics were found in all analysed rivers; for the Rhine they estimated a transport of 20–30 tons per year into the North Sea.

A more recent and more detailed study was published in 2018 about microplastics in inland waters in South and West Germany [10]. To generate a homogeneous dataset for a larger geographic area, five German federal states started a study together with the University of Bayreuth. They analysed microplastics in rivers in South and West Germany, including several sampling sites in the Rhine catchment area. Qualitative and quantitative analyses of microplastics were performed in different compartments, including 52 sampling sites at the river surface. The results of these surface samples showed that microplastics are present at all sampling sites. Therefore, microplastics can be evaluated as ubiquitous.

The found concentrations range between 2.9 particles/m^3 in the Rhine in Nackenheim, south of Mainz, and 214 particles/m^3 in the Emscher, when pouring into the Rhine. Although there were many similarities, also regional differences were identified. The dominant form of microplastics was fragments.

The study showed that methods for sampling and analysis are not evolved enough to perform a continuous and coherent monitoring of microplastics. They recommend to take measures for the reduction of further inputs to avoid the accumulation of this highly persistent material. This acts as a precautionary principle, even though the effects of microplastics are not clear yet. Besides, further research is recommended, e.g. for the identification of relevant input pathways, to make measures more efficient.

Besides the studies, which give a first insight into the load situation, BKV GmbH, representing all parts of the plastics industry, together with the Consultic GmbH developed a model [11] to estimate plastics coming from land into the sea. Some first results estimated the plastic load coming from Germany into the North Sea between 500 and 3,500 tons per year. This model will be updated and improved with monitoring data, when available.

4 Initiatives in the Countries in the Rhine Catchment

Regarding plastics there are many research projects, workshops, conferences and other initiatives in the countries in the Rhine catchment.

In Austria plastics were analysed in the Danube. Although it is a different river system, the results can help with methodological questions and can give an insight into the load situation. The study [12], presented in 2015, developed an innovative method suitable for big rivers. It showed that the Austrian contribution to plastics in the Danube is relatively low and that 90% of the plastics entering the Danube have diffuse input pathways. Sources are, e.g. incorrect handling, degradation of bigger plastic parts and littering. Input pathways can be surface run-off, wind and waste water.

Based on this study, Austria initiated a measurement programme including the "zero pellets pact" with the chemical industry, the end of microplastics in cosmetic products and to increase the awareness for the topic on EU level.

In Switzerland a first study about the load situation with microplastics was conducted in 2013 [13]. The samples were taken mostly in big lakes and their shores but also in fish and water birds. Everything was analysed for particles with a size of 0.3–5 mm. The results showed around 0.1 microplastic particles per m^2 water surface and around 1,000 microplastic particles in sand (down to 5 cm depth). For the only analysed river Rhone, the study estimated less than 14 kg discharge of microplastics per day.

In a second study [14], the discharge of microplastics from waste water treatment plants, storm overflow, road drainage and small inflows in Lake Geneva were analysed. The retention capacity of waste water treatment plants was estimated to be more than 90%. However, during rainfall events, discharges of microplastics are much higher.

In general, the influence of microplastics on water quality was estimated to be relatively low in Switzerland, compared, e.g. to the pollution with pesticides. When it comes to measures, Switzerland focusses on the sources. Therefore, a round table, with representatives of the Swiss Federation, the cantons, cities and villages as well as representatives of the retail business and the plastic industry, was started related to recycling and to littering.

In Germany plastics are an important topic, especially when it comes to the implementation of the MSFD, and there are several events and conferences regarding this topic. The planned measures include measures to reduce the production and consumption of plastics (e.g. reduced usage of primary microplastics), to reduce littering and other input pathways (e.g. deposit system) and to reduce plastics already in the system (e.g. fishing for litter concept) and educational measures (e.g. including the topic in school curriculums). Since March 2016 there is a round table about marine litter, which focusses on the implementation of the planned measures (see Werner et al. in Chap. 2.13).

There are nonbinding agreements with the industry. A large part of the cosmetic industry agreed to stop using microplastics in cosmetics, and the trade association in Germany agreed to stop giving plastic bags for free [15].

To estimate plastic waste coming from land, a model was developed, which is continuously improved and updated with real data (BKV GmbH, see Sect. 3).

"Real data" is gathered during different studies on national and state level, like the study on microplastics in inland waters in South and West Germany mentioned in Sect. 3 [10].

There are many scientific studies about plastics in Germany at the moment, which will improve our knowledge in the next years. One of the biggest cross-disciplinary research projects in Germany is funded by the German Federal Ministry of Education and Research [16]. There are 18 projects under the complex of topics "Plastics in the Environment – Sources, Sinks, Solutions", which are conducted by 103 institutes. The main topics are green economy, consumption, recycling, freshwater ecosystems and saltwater ecosystems. The projects started in 2017 and will end in 2021.

In France there are several national plans to reduce plastic waste. For example, one goal of the plan for biological diversity published in 2018 [17] is that in 2025 no plastic is disposed into the sea. To reach this goal, several measures are designated. Until 2022 some articles like balloon sticks should be prohibited, packaging made of recycled or biological degradable material should be promoted, accumulation areas for macroplastics in rivers should be identified and cleaned, and until 2022 there should be filter systems to catch plastic particles in waste water streams of big production areas or big application areas.

In the French management plans for the Rhine and the Maas, several recommendations were made to reduce waste in the aquatic environment [18], and France offered financial support for some of these measures.

In Luxemburg there are different initiatives, like "eco sac" to avoid single-use bags at the counter. It is based on an ecological bag made out of 100% recyclable materials, which was for free at the beginning and can now be bought for 0.70 €. Since the beginning of the initiative in 2004, more than 841 Mln. single-use bags were avoided.

Luxemburg also has a waste management plan with ambitious goals. Materials should be managed ecologically and should be economically sustainable. For example, the SuperDrecksKëscht® is an important part in this plan. The six pillars of this brand are (1) animation, information, sensitisation, training and further education, as well as (2) ecological waste management in the company, (3) intelligent and sustainable consumption, (4) the SuperDrecksKëscht® and her business and association partners, (5) the SuperDrecksKëscht® and her partners in local and social authorities, and (6) ecological waste management [19].

Until 2022 littering should be zero. To reach this goal, Luxemburg launched multimedia campaigns and is organising clean-up campaigns to sensitise the public.

In the Netherlands the highest priority is on secondary microplastics, based on a study which estimated emissions. This concerns especially litter with a focus on packaging and disposables.

There is an integral national approach on litter (Framework Contract Packaging 2013–2022 [20, 21]). This includes the development of a deposit system for small PET bottles (a deposit system for big PET bottles already exists) and beverage cans; the increased motivation for clean behaviour; the focus on different hotspots, like shopping centres and areas of public transport, the responsibility of producers and the improvement of knowledge. There are also different organisations working on the subject, like "NederlandSchoon" [22], an organisation financed by the packaging industry. It is concerned with product development, projects together with the economy and the support of local authorities. It focusses on enforcement, cleaning, waste bins, rewarding cleanliness and monitoring.

When it comes to primary plastics, the Netherlands focusses on the ban of microplastics in cosmetic products, the reduction in other sources and the cooperation on EU level.

There are also several studies, analysing, e.g. how plastics can be measured and monitored. For example, in the project TRAMP [23], running from 2015 to 2019, the goal was to develop technologies to detect nano- and microplastics in environmental samples; to develop technologies to assess fate, hazards and effects of plastic in the freshwater environment; and to provide a prospective assessment of the present and future risks of plastic in the freshwater environment.

When it comes to measures, there are several clean-up campaigns along the rivers, like Schelde and Maas [24], and initiatives to remove plastics from water, e.g. in the ports of Rotterdam [25] and Amsterdam.

Regarding initiatives and measures for the marine area, the Netherlands is of special interest as the whole Rhine delta is located in the Netherlands. The measures include measures at the beaches, agreements with the fisheries, agreements with the shipping industry, measures during production, education and sensitising programmes and bringing the topic on the agenda in the catchment areas.

5 Initiatives on the International Level

There are several initiatives on plastics on the international level but so far none specific for the Rhine river basin.

On the EU level, the decision to ban specific plastic disposables, like plastic straws, gained a lot of attention recently. This single-use plastic directive [26] includes EU-wide rules to target the ten single-use plastic products most often found on Europe's beaches and seas, as well as lost and abandoned fishing gear. This might help to reduce marine litter significantly, as they constitute together 70% of all marine litter items.

But there are many more regulations and initiatives which help to reduce inputs of plastics in waters. For example, the Directive (EU) 2018/852 [27] amending Directive 94/62/EC on packaging and packaging waste has the target to prevent the production of packaging waste and to promote the reuse, recycling and other forms of recovering of packaging waste, including quantitative recycling targets.

And the Directive (EU) 2015/720 [28] amending Directive 94/62/EC has the goal to reduce the consumption of lightweight plastic carrier bags, which was very successful so far and brought a rapid shift in consumer behaviour.

In general, the EU is quite active when it comes to waste management and circular economy. Concerning plastics, the EU even developed a European Strategy for Plastics in a Circular Economy [29]. This strategy addresses the design, the production, the use and the recycling of plastics. The goal is to have a better design of plastic products, a higher recycling rate and more and better recyclates. There is also the possibility that the question of waste is included in the water framework directive during the revision. So far it is not part of the WFD but only part of the MSFD.

Besides regulations, the EU supports or even commissions scientific studies. For example, the study "Identification and Assessment of Riverine Input for (Marine) Litter" [9] gave an insight into the amount of plastic particles between 0.3 and 3.2 mm, transported with the surface layer of rivers into the sea. The two samplings of the Rhine at Rotterdam resulted in estimates of 21 and 30 tons/year marine input of plastic litter, although the numbers must be treated carefully due to very variable measurements.

Another important aspect of the EU initiatives is conferences. Several of them have taken place since 2015. For example, in May 2015 there has been a conference in Brussels on the topic "Eliminating Plastic and Microplastic Pollution – un urgent need" [30]. In June 2016 in Berlin, there has been the European Conference on Plastics in Freshwater Environments, which was addressing issues like monitoring, risks, sources and management options [31]. In 2017 there was an expert conference in June in Brussels dealing with "Recommendations towards the EU Plastics Strategy" [32] and a stakeholder conference in September in Brussels where stakeholders could participate in the discussion about the European strategy for plastics [33].

Besides the EU, the regional sea convention OSPAR (Oslo and Paris Commissions) is concerned with the topic of waste and especially plastics in the sea. In 2014 they adopted the Regional Action Plan (RAP) on Marine Litter [34], which describes actions for common measures and goals. The goal is to substantially reduce marine litter in the OSPAR maritime area by 2020 so that properties and quantities of litter do not cause harm to the marine environment. The RAP, which was agreed on for the time period 2014–2021, contains collective and national actions. They are addressing land-based and sea-based sources, as well as education and outreach and removal actions. The ICPR member states Germany and the Netherlands are leading the development of many measures.

During an OSPAR workshop in 2015, most important sources and possible measures were discussed. The conclusion was that fibres and clothing, scrubbing cleaning agents, colour, tires, plastic pellets and granulated material of playgrounds are of special interest. The discussed measures focussed on the source, which should be preferred against "end-of-pipe" solutions.

OSPAR also addresses the riverine input into the sea. They organised a survey amongst the river commissions regarding plastic and a workshop in Bonn called "OSPAR Riverine and Marine Litter Work Session" in 2017. The goal is to have a

good information exchange between the experts and harmonise the approaches in marine and riverine areas.

6 Plastics as a New Topic for the ICPR?

The ICPR can look back on a long and successful history. The work of the ICPR helped to improve the situation of the Rhine and the focus and work topics expanded over time. In the beginning the focus was to improve water quality. The Rhine was known as the sewer of Europe, because of big cities and many industry sites, which discharged their waste water (nearly) untreated into the Rhine. Nowadays the industry sites and 96% of the population in the Rhine catchment are connected to waste water treatment plants (according to the European urban waste water directive (91/271/EEC)), and the water quality increased significantly.

In the 1980s, after the so-called Sandoz catastrophe in 1986, a new ambitious programme [35] was started including also ecology. During the Sandoz catastrophe, tons of heavily toxic pesticides flowed into the Rhine with the fire extinction water in the area of Basel (Switzerland). This caused the death of all aquatic life downstream up to several 100 km, and it provoked a huge reaction in the public and changed the political discussions to a more long-term and ambitious goal setting. This programme resulted in an increased awareness concerning ecological questions and helped to improve the situation for fauna and flora in the Rhine catchment.

In the 1990s again, a catastrophe, the two centennial floods along the Rhine, changed the programme of the ICPR. An action plan on floods [36] was started, and nowadays floods and also low water issues are part of the working programme.

Looking back on this history, the ICPR proved to be able to react on upcoming topics in a constructive way. Even catastrophic events turned into ambitious and successful programmes. Although there is still a lot of work to do, for example, when it comes to river continuity or micropollutants, the programmes were successful, and the situation of the Rhine improved in all main work areas.

Additionally, the ICPR has a well-functioning organisation structure and monitoring network. The countries in the Rhine catchment area have a good basis of understanding and are used to work together in the ICPR.

These prerequisites enable the ICPR to deal with the upcoming topic of plastics. Already since 2013 there is an information exchange about initiatives in the countries regarding plastics. The ICPR is attending workshops and conferences to keep up to date and share experiences and information.

Thanks to recognised observers, there is also information exchange, for example, with the chemical industry and with several NGOs for nature protection, which are already active in the field of plastics, e.g. with clean-up campaigns.

The ICPR collected studies about plastics, performed in the Rhine catchment area. This gave a first overview and a better basis for the ongoing discussions. Unfortunately, the studies so far indicate that a general monitoring is not possible at the moment, as methods available so far are very time-consuming and no

standardised methods are available. Therefore, the ICPR is not monitoring plastics in the Rhine so far. When there will be suitable methods for the monitoring, the ICPR can build on the already existing monitoring network. In the Rhine catchment area and especially along the main stream, there are monitoring stations to monitor especially water quality. In several stations there is even a continuous monitoring, and the stations are well equipped with sampling tools and analytical methods. There is an expert group dealing with the monitoring and therefore providing the valuable information exchange between the countries and the monitoring stations. This network of monitoring stations was improved and stabilised since 1950. A possible monitoring of plastics could build on the infrastructure and the knowledge in the already existing monitoring stations and could benefit from the close information exchange in the ICPR.

The ICPR also collected information about sewage sludge application on land in the countries, as it can be one of the input pathways. The survey showed that most of the sewage sludge in the Rhine catchment area is burned and that the percentage of burned sludge will even increase, based on the decisions of the countries for the coming years.

Another field of interest of the ICPR is the communication with the public. Especially when it comes to littering, the information and sensitisation of the broad public is an important topic. The ICPR informs about plastics on its homepage and gives information to questions coming from the press and the public. Also a good communication with the NGOs about plastics is important, as the NGOs are already active with flyers and events.

Although there is a consensus in the ICPR that plastics do not belong in rivers and seas and measures should be taken, even if not all effects are clear, it is not a water management problem in the first place. There are other sectors involved, like waste management, waste water management, industries and municipalities. Measures are most effective directly at the source, and the water management sector is only at the end of the pipe. The ICPR would appreciate initiatives also in the other sectors and measures along the chain, from production, over consumption, till the products are disposed and possibly recycled. For many questions and measures, a solution on the EU level is recommendable. And the EU initiatives, like the ban on some single-use plastics or the strategy to reach a more circular economy with regard to plastics, can be a big support for the reduction of plastics in the environment.

Also, projects including the industrial sector, like the before mentioned ban of microplastics in cosmetics, can be helpful and are welcome from the water management side. Another good example is the worldwide alliance against plastic waste in the environment founded in January 2019 by 30 companies, including several big companies from the chemical industry. The main topics are waste management, recycling, education and clean-up. The overall goal is to prevent plastics ending up in the environment [37].

The information exchange in the ICPR will continue, and new developments as well as possible reactions will be discussed. Depending on the results of ongoing and planed studies, as well as new developments, e.g. on the EU level, there are several options for the ICPR to take action. These focus mainly on providing a platform for

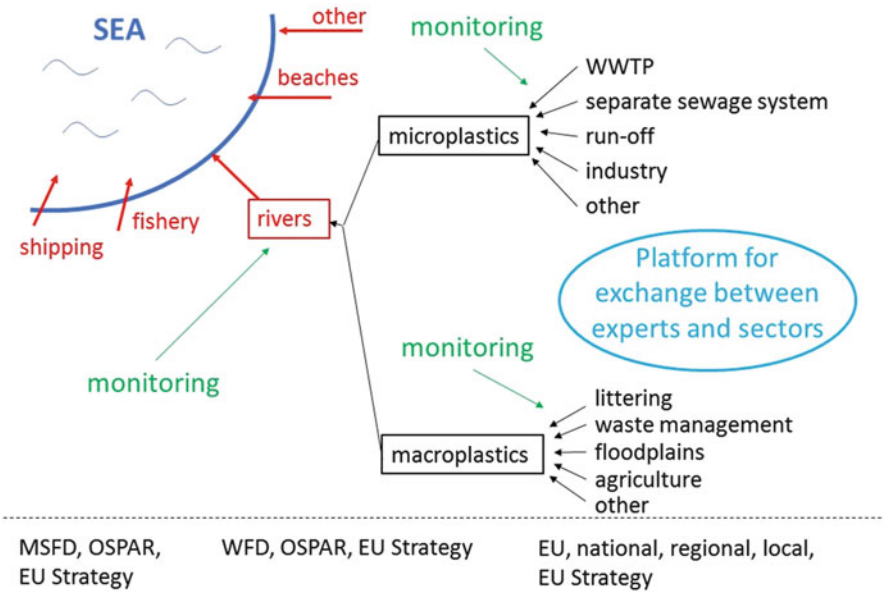

Fig. 3 Overview of input pathways into the sea (in red), sources for micro- and macroplastics (in black) and possible actions for the ICPR (in green and light blue). On the bottom a non-exhaustive list of regulations is given for the different areas. The mentioned input pathways are non-exhaustive and not weighted in dominance. Possible actions for the ICPR are hypothetical and can be adopted based on further scientific results or political settings. The possible monitoring would be performed by the countries and federal states; the ICPR would be the coordinating body. © Stötter and Van Dokkum

experts and sectors for information exchange and monitoring on different levels and places (see Fig. 3).

In general, the ICPR could be active on different levels and with different focusses including methodology (e.g. information exchange of experts and possible harmonisation), monitoring, public relations (e.g. internationally coordinated clean-up campaigns or flyers) and measures (e.g. recommendations and workshops). Nevertheless, it is important that the relevant sectors take action as far as possible to prevent more plastics ending up in the rivers and seas.

7 Conclusions

Plastics in rivers, also in the Rhine, is an upcoming topic and already widely discussed in politics, press and the broad public.

In the ICPR there is a regular information exchange since 2013 about research projects, workshops, conferences and other initiatives in the countries in the Rhine catchment. The countries are already active, and there are new developments and

results on short intervals. The load situation and the focus of the countries differ. For example, Switzerland found relatively low concentrations of plastics and estimated its influence on water quality as relatively low, e.g. compared to pesticides, whereas the Netherlands has to deal with higher plastic concentrations and has action plans against it, especially in marine areas.

So far, there are no (or not yet) methods available to perform a regular monitoring. Therefore, the ICPR is only collecting information of scientific studies performed in the Rhine catchment and is not monitoring itself. The available studies show variable concentrations of plastics, and it is difficult to rely on absolute numbers. Nevertheless, the studies show that plastics are of ubiquitous occurrence. Based on the idea of prevention, it is necessary to reduce inputs of plastics into the environment, including rivers.

Measures to prevent inputs of plastics range from measures in the industry sector, like the voluntary ban of microplastics in cosmetics of some companies; measures to steer the consumer, like deposit systems; to cleaning campaigns along rivers and the beaches.

Inputs of plastics should be reduced at the source as far as possible. Therefore, it is not a topic for water management in the first place. Other sectors, like waste management and industry have to get active or are already active to a certain extent to reduce the input.

Possible actions for the ICPR are already discussed but postponed until more information and suitable techniques are available. Besides, the information exchange in the ICPR, between the countries in the Rhine catchment and with the IGOs and NGOs in the ICPR, will continue.

It can be expected that the data basis will improve in the coming years, as many research studies are ongoing at the moment.

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Five Years Since the 2013 HELCOM Ministerial Declaration

Marta Ruiz and Monika Stankiewicz

Contents

Abstract HELCOM (Baltic Marine Environment Protection Commission – Helsinki Commission) is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, the Helsinki Convention. Contracting Parties to the Convention are Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. They all gathered more than 40 years ago to achieve a common goal: to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental cooperation. Time has passed, and new pressures threaten to jeopardise the achievement of such a goal, among which marine litter is an issue of concern. HELCOM official starting point on this topic dates back to 2013 when countries committed to significantly reduce marine litter by 2025, compared to 2015, and to prevent harm to the coastal and marine environment as part of the 2013 HELCOM Ministerial Declaration. This chapter aims at analysing what has happened in these almost 5 years with a focus not only on plastic but on marine litter as a whole: are there appropriate monitoring programmes in place for the different aquatic compartments? Do we have enough monitoring data to evaluate trends? Do we know which the main sources of marine litter to the Baltic Sea are? Are there regional actions in the

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HELCOM Regional Action Plan on Marine Litter (2015) addressing these sources? Things can always be done better, but it is important to recognise steps taken forward as well.

Keywords HELCOM, Marine litter, Plastics, Regional cooperation

1 HELCOM Commitments on Marine Litter

The Baltic Sea is nearly a landlocked sea, only connected to the greater ocean by narrow straits. Other unique feature is its salinity: being a brackish environment limits the number of species present. Also, compared to an open ocean, the Baltic Sea is a rather small sea, almost like a big lake. Due to these natural characteristics, input of pollution will affect the Baltic Sea and become visible much faster than, for example, in the Pacific Ocean. A particular concern for the Baltic Sea is the wide and increasing distribution of areas with poor oxygen conditions. Restoring the marine environment of the Baltic Sea is therefore particularly challenging. Many other semi-enclosed seas and coastal areas in the world face a similar challenge.

All areas in the Baltic Sea fall within national jurisdiction. There are nine coastal countries (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden) around the Baltic Sea, and some 85 million people are living in its drainage area. Within HELCOM – a Regional Sea Convention involving these nine coastal countries and the European Union – coordinated environmental management across national borders has already been taking place since 1974. This cooperation is based on a regional treaty – the Convention on the Protection of the Marine Environment of the Baltic Sea (Helsinki Convention of 1974, amended in 1992) [1]. Even though the recommendations are not legally binding as such, the fact that they are adopted unanimously, and that countries are required to report on their national implementation, diminishes concerns about their lacking legal nature.

While the Convention does not specifically mention plastics, its provisions are applicable to all types of pollution, de facto relating to marine litter – including plastics. According to Article 3 of the Convention, "the Contracting Parties shall individually or jointly take all appropriate legislative, administrative or other relevant measures to prevent and eliminate pollution in order to promote the ecological restoration of the Baltic Sea Area and the preservation of its ecological balance". Furthermore, according to Article 6, "the Contracting Parties [shall] undertake to prevent and eliminate pollution of the Baltic Sea Area from land-based sources [. . .] in the catchment area of the Baltic Sea".

Shipping as a source of pollution has been specifically regulated by the Convention, in line with the requirements of the International Maritime Organization (IMO). Thus, the longest record of HELCOM actions and measures to address discharge of waste – and implicitly, plastics – to the sea is related to shipping. There is a general prohibition of dumping to the Baltic Sea Area (Article 11). "Dumping" means any deliberate disposal at sea or into the seabed of wastes or other matter from ships,

other man-made structures at sea or aircraft and any deliberate disposal at sea of ships, other man-made structures at sea or aircraft. The exception is disposal of dredged material, if the criteria specified in Annex V of the Helsinki Convention are met, as well as under specific circumstances when dumping is the only way to ensure safety of human life. Already in 1973, the Baltic Sea was designated as a special area for discharge of garbage from ships under the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex V (in effect from 1 October 1989). Based on this status, the discharge of Annex V waste – which includes plastics – from a ship into the Baltic Sea area is more restrictive than the general provisions of MARPOL Annex V. The only allowed discharges, if resulting from normal operation and discharged outside 12 NM (nautical mile), are the following: ground or comminuted food waste, cargo residues and cleaning agents in cargo hold wash waters as well as deck cleaning agents in deck wash waters (Maritime Assessment, 2018 [2], p. 88). It is also mandatory for ships operating in the Baltic Sea to discharge all ship-generated wastes to a port reception facility before leaving the port (Regulation 6 of Annex V of the Convention).

The HELCOM No Special Fee Recommendation (HELCOM Recommendation 28E/10 [3]) is the first HELCOM recommendation specifically addressing marine litter. It applies to garbage as well as litter caught in fishing nets (based on the amendment from 2007), in addition to other types of waste. According to the "no-special-fee" system, a fee covering the cost of reception, handling and final disposal of ship-generated wastes is levied on the ship, irrespective of whether ship-generated wastes are actually offloaded or not.

The Baltic Sea Action Plan [4], a comprehensive programme devised to achieve good environmental status of the Baltic Sea and adopted by the Baltic Sea countries and the EU in 2007, also addresses marine litter, even if only concisely. The Contracting Parties committed to encourage projects by local governments and local communities to remove litter from the coastal and marine environment, such as beach clean-up operations, "Fishing for litter" initiatives and local litter campaigns, noting the leading role of the voluntary sector in such activities.

Recommendation 29/2 "Marine litter in the Baltic Sea" adopted in 2008 was the first HELCOM Recommendation entirely devoted to marine litter and largely focusing on sampling and reporting of marine litter found on beaches [5].

The 2010 Moscow HELCOM Ministerial Meeting [6] includes a commitment of the Contracting Parties to "take further steps to be able to carry out national and coordinated monitoring of marine litter and identify sources of litter". The current HELCOM monitoring guidelines for marine litter on beaches [7] de facto supersede this Recommendation, even though a related formal process in HELCOM is yet to be finalised.

But it was only at the Copenhagen HELCOM Ministerial Meeting in 2013 [8] that marine litter was recognised as a topic that requires a comprehensive response. HELCOM countries committed to significantly reduce marine litter by 2025, compared to 2015, and to prevent harm to the coastal and marine environment. Furthermore, HELCOM countries decided to develop a regional action plan by 2015 at the latest with the aim of achieving such ambitious objective. The process to develop the

action plan started in 2014. Two regional expert workshops and one meeting at an intergovernmental level were conducted to develop the Action Plan. In 2015, a brand new HELCOM Regional Action Plan on Marine Litter was adopted by Contracting Parties as HELCOM Recommendation 36/1 [9], containing concrete regional actions and voluntary national actions to reduce the input and presence of marine litter in the Baltic Sea.

The Action Plan focuses on concrete measures for preventing and reducing marine litter from its main sources. Furthermore, it has required that common regional indicators and associated definition of good environmental status (GES) related to marine litter are developed and coordinated monitoring programmes for those indicators are established. And, last but not least, the Action Plan calls for cooperation with stakeholders, from civil society groups to business and industry, to promote the removal of litter from the marine environment in a practical, feasible and environmentally sound manner and the development of best available techniques (BAT) and best environmental practice (BEP) for that purpose. The need to continued cooperation with other relevant regional and global organisations and initiatives to combat marine litter is another component of the plan.

In the Ministerial Meeting [10] held on 2018, HELCOM countries reiterated their commitment of achieving a significant quantitative reduction of marine litter by 2025. In addition to developing baselines, quantitative targets and harmonised monitoring methods for marine litter, the HELCOM Ministers expressed their support to measures aimed at preventing plastics – including microplastics – from contaminating the marine and costal environment. Such measures should address the entire life cycle of products and examine efficient and cost-effective options to reduce plastic and microplastic releases from products and processes into the marine environment. The Contracting Parties have also decided to develop appropriate measures to address microplastics in riverine inputs, urban wastewater effluents as well as storm water based on an increased knowledge on the scale of the problem.

2 Marine Litter Monitoring

Knowing what is out there, in the beaches of our region, in our seabed and in the water where we swim is key to efficiently implement the actions needed to reduce the presence of marine litter in all these compartments. At the time of the Action Plan adoption, back in 2015, there was no Baltic Sea wide knowledge on amounts of marine litter. However, this did not prevent HELCOM countries from initiating a challenging and ambitious action plan drawing from experiences in other European seas such as in the Mediterranean and in the North-East Atlantic areas. Improving the knowledge on the status of the Baltic Sea in relation to marine litter, including based on monitoring data, was an obvious need.

There is currently no regionally coordinated monitoring of marine litter in the Baltic Sea. However, work is ongoing to develop two subprogrammes, on "Macrolitter characteristics and abundance/volume" [11] and on "Microlitter particle

abundance and characteristics" [12]. HELCOM countries have, to varying degrees, developed national monitoring programmes concerning macroscopic litter on the beaches, water surface, seafloor and in biota and microlitter in the surface water and sediments. The information on the status of the monitoring programmes is regularly updated to HELCOM.

In terms of indicators, work is ongoing to develop three HELCOM indicators on litter: HELCOM pre-core indicators on beach litter and litter on the seafloor and HELCOM candidate indicator on microliter in the water column. In HELCOM, indicators have three levels of development, candidate, pre-core and core indicators, the latter one representing the fully developed indicator.

A core indicator describes a scientifically sound phenomenon and is based on measurements, observations or validated models. Whenever ecologically relevant, core indicators are Baltic-wide. The area of applicability is expressed through HELCOM assessment units defined in the HELCOM Monitoring and Assessment Strategy [13]. They are commonly agreed among HELCOM countries based on commonly adopted quantitative threshold values or environmental targets. State core indicators evaluate the status against a quantitative threshold value, whereas pressure core indicators measure the progress towards an environmental target. The threshold value or environmental target, the indicator assessment protocol and the general indicator concept are described in detail in the core indicator report. A core indicator measures the progress towards reaching a Baltic Sea Action Plan (BSAP) objective. For those Contracting Parties that are also EU Member States, the core indicators can also be used to assess criteria under the EU Marine Strategy Framework Directive (MSFD).

Criteria for fully operational HELCOM core indicators are as follows:

(a) The scientific concept/design of the indicator:

- Detailed description of the concept developed
- Scientific background for the concept described and the type of data is supporting the concept
- Referenced and reviewed
- Connection to anthropogenic pressures qualitatively or quantitatively clarified as appropriate for the indicator
- Policy relevance and links to legislative targets clearly described
- Ecologically relevant areas (HELCOM assessment units) where the indicator is applicable are described

(b) Assessment protocol: described in sufficient detail for any expert to process monitoring data (e.g. statistical processing) and compare the outcome to the threshold value/environmental target

(c) Threshold value/environmental target:

- Threshold value/environmental target adopted.
- Quantitative value clearly presented, where relevant as assessment unit specific values.
- Underlying concept described and relevant supporting references given.

- Trend-based threshold values/environmental targets are provisional and are considered to require further development work and a review in 5 years' time with the aim of determining a quantitative value.
- Confidence of the appropriateness of the threshold values is to be given.
- Applicability of the threshold value should be demonstrated for a selected area.

(d) Coordinated monitoring and methodology:

- Technical guidelines described, joint HELCOM monitoring described through the HELCOM Monitoring Manual, guidelines to be detailed and accessible for all users
- Optimal monitoring (frequency and sampling strategy) that provides a high-confidence indicator evaluation described, identifying possible gaps in the current monitoring
- Appropriate quality assurance in place

(e) Data management arrangements:

- Description of data flow (sampling, analysing, hosting).
- Quality assurance routines in place for data.
- Snapshot datasets of the underlying data to each indicator evaluation made available.

Pre-core indicators have been identified as necessary by the HELCOM Contracting Parties for BSAP and MSFD purposes. The indicator, usually under development, has not yet been agreed upon as a core indicator, typically because some aspect of the indicator is underdeveloped, i.e. all criteria of a fully operational core indicator are not met and/or agreement on the indicator among the Contracting Parties of HELCOM may not have reached a full consensus. Contracting Parties of HELCOM should aim to monitor the parameters relevant for the pre-core indicator, with the understanding that the pre-core indicators can be based on compilations of data from sources other than coordinated HELCOM monitoring data. When a pre-core indicator has been further developed so that it meets the criteria of a core indicator, it can be proposed to be shifted to a core indicator status by a HELCOM working group. Agreement on core indicators and adoption of threshold values or environmental targets are made by HELCOM or HELCOM Heads of Delegation.

Candidate indicators are indicators on which there is not yet sufficient understanding of the concept but where a need for an indicator has been identified to cover gaps in the requirements of the BSAP or the MSFD. The stage of development of the content of the indicator is completely or severely lacking, and/or there is no common agreement on the indicator among the Contracting Parties. New indicators are first proposed as candidate indicators by HELCOM expert groups or projects. After subsequent development and testing of the indicator, it can be proposed to be shifted to a pre-core indicator status by a HELCOM working group if it fulfils the requirements of a pre-core indicator. The candidate indicator list is a living document and should be considered as expert level proposals for new core indicators.

Work on indicators is taken forward through the "lead country approach". Poland is the lead country developing the beach litter indicator, with Denmark and Sweden as colead countries. For the indicator on litter on the seafloor, there is no lead country but two colead countries, Denmark and Sweden. On microlitter in the water column, the indicator is led by Finland, with Denmark and Sweden as colead countries.

The status of development of these indicators can be consulted in their respective indicator reports [14–16]. As a summary, it can be said that for beach litter, the indicator concept is the trend of the number of litter items per category group (artificial polymer/materials, rubber, cloth/textile, paper/cardboard, processed/worked wood, metal, glass/ceramics and others) per 100 m beach segment, an interim definition of GES is proposed, and data and information available in the Baltic Sea area are compiled. However, the status is not assessed due to lack of agreement on GES.

The indicator on litter on the seafloor is at a similar level of development, where the indicator concept is the amounts of litter (items per km^2 seafloor) in different categories of litter items (plastic, glass/ceramics, metals, natural products, rubber and miscellaneous), distributed in different subbasins. The data stems from marine litter collected in trawls during fish stock surveys, which is only an indication of the actual amount of litter on the seafloor. An interim definition of GES is proposed, and data and information available in the Baltic Sea area has been compiled, but the status is not assessed due to lack of agreement on GES.

The development of monitoring guidelines for marine litter on beaches [7] which are now adopted at HELCOM level contributes to the further development of the beach litter indicator.

As already indicated, the indicator on microlitter is the less developed indicator. This is partly due to the difficulties of harmonising sampling and analysing methodologies for microlitter, which also applies to microplastics. Moreover, there is a discussion at the expert level on the adequacy of studying the sediment compartment rather than the water column to achieve a better understanding of the status of the marine environment in relation to this criterion. It is also essential to formulate a common reporting format which includes metadata (i.e. matrices, sampling stations categories, equipment, etc.) and data on monitored parameters (e.g. size and particle shape categories, information on materials and concentrations), which will eventually enable the development of a regional database on microlitter and microplastics. These were the main conclusions extracted from the work conducted in 2017, as part of the EU co-funded project SPICE ("Implementation and development of key components for the assessment of Status, Pressures and Impacts, and Social and Economic evaluation in the Baltic Sea marine region"), to compile and analyse data on microlitter in the region, which also mapped spatial coverage of research and pilot monitoring for water surface, water column and sediment [17].

Recently, HELCOM countries in their Ministerial Declaration 2018 committed "to strengthening regional research and developing harmonised monitoring methods on the sources, distribution, amounts and impacts of marine litter including microplastics, in coherence with similar work undertaken by Contracting Parties in other relevant fora, and to improving assessment of the effectiveness of measures". Thus,

the need to continue working on monitoring marine litter with a regional perspective is recognised.

3 Assessment of Marine Litter in the Baltic Sea

The "Second HELCOM Holistic Assessment of Ecosystem Health in the Baltic Sea" that was carried out by HELCOM through the HELCOM HOLAS II project [18] reflects the environmental situation in the Baltic Sea for the period 2011–2016. The assessment covers the whole Baltic Sea marine region and provides information on the overall environmental status of and pressures on the Baltic Sea as well as social and economic aspects that are linked to the status of the Sea and the human activities impacting upon it. In June 2017 the assessment was published under the title "State of the Baltic Sea report, June 2017", containing, for the first time in a regional assessment, a descriptive section on marine litter (since there are no core indicators on marine litter). The section on marine litter was updated as part of the update of the report concluded in June 2018 ("State of the Baltic Sea – Second HELCOM holistic assessment 2011–2016" [19]); thus the final version includes information on (1) litter items found on beaches, per subbasin, grouped by material (plastics, metal, glass/ceramics, paper/cardboard, processed/worded wood, rubber, cloth/textile and unclassified); (2) litter items found on different types of beaches, categorised into urban, peri-urban and rural beaches, again grouped by material; (3) the 10 most frequent litter items at Baltic Sea level at the different types of beaches; and (4) the proportion of marine litter material categories in bottom trawl hauls for subbasins covered by the Baltic International Trawl Survey coordinated by the International Council for the Exploration of the Sea (ICES).

What we know now, after this huge exercise of compilation and analysis of data, is that among the different categories of material considered, plastics are the main component of the litter items found on our beaches (Table 1). Furthermore, it seems that we left behind a lot of items when visiting our beaches for recreational purposes, since the most frequently occurring ones are attributed to eating, drinking or smoking activities, such as food wrappings, bottles or lids, as well as plastic pieces of different sizes. These items are common in all parts of the Baltic Sea, together with items related to industrial packaging, such as sheeting, strapping bands and masking tape (based on data from 15 subbasins). Derelict fishing gear is among the 20 most common items in the Eastern Gotland Basin, Gdansk Basin and Kiel Bay. It is noteworthy that balloons or balloon-related items are found among the top 10 items in 9 of the 15 subbasins (see Fig. 1).

When it comes to seafloor litter, attention is to be paid to the fact that since data available comes from fish trawling surveys, there is no data from those areas where these surveys do not take place, e.g. shallow water areas or complex substrates and the Gulf of Bothnia. From the available data, it can be stated that items made from natural materials, such as wood, natural fibres and paper, and plastic items dominate in most subbasins. Slightly over half (58%) of the 1,599 hauls reported in

Table 1 Ten most frequent litter items at Baltic Sea level at different types of beaches, categorised into urban, peri-urban and rural beaches

Rank	Urban beach	Peri-urban	Rural beach
1	Drinking related items such as cups, caps, lids (plastic)	Plastic and polystyrene pieces	Plastic and polystyrene pieces
2	Plastic and polystyrene pieces	Food related items such as wrappers, packets (plastic)	Food related items such as wrappers, packets (plastic)
3	Cigarette butts and remains.	Cigarette butts	Drinking related items such as cups, caps, lids (plastic)
4	Food related items such as wrappers, packets (plastic)	Drinking related items such as cups, caps, lids (plastic)	Plastic bags
5	Paper and cardboard items	Plastic bags	Bottles and containers (plastic)
6	Drinking related items such as bottle caps, pull tabs (metal)	Single-use cutlery and straws	String and ropes (plastic)
7	Plastic bags	Drinking related items such as bottle caps, pull tabs (metal)	Cigarette butts
8	Single-use cutlery and straws	Glass and ceramic fragments	Glass and ceramic fragments
9	Bottles and containers (plastic)	Foil wrappers and pieces of metal	Industrial packaging
10	Drinking related cans (metal)	String and ropes (plastic)	Processed wood and pieces of processed wood

The colours identify items categorised as plastics (artificial polymer materials; grey), paper or cardboard (purple), metals (orange), glass or ceramics (green) and processed wood (blue). The results are based on data from Denmark, Estonia, Finland, Germany, Lithuania, Poland and Sweden. Data for reference beaches in Denmark are included under rural beaches. For each survey, the 20 most frequently sampled items were listed, and scores were given to each item. After this, the results for different surveys were merged to provide a regional list of top 10 items. Only data from seasonally monitored sites are included, to prevent from overestimating occasional events [20]

2012–2016 contained marine litter items [21]. Plastic was the most common litter material category at the Baltic Sea scale, constituting on average around 30% of the number of items and 16% of the weight. A weak but statistically significant increase in seafloor litter representing non-natural materials was seen over the studied period.

4 Implementing the Regional Action Plan on Marine Litter

The regional implementation of the Action Plan is led within HELCOM by the Pressure Group (Working Group on Reduction of Pressures from the Baltic Sea Catchment Area), who also coordinates it with relevant subsidiary bodies to enable their substantial contribution. The status of implementation of the Plan is regularly considered during Pressure meetings, which are held twice a year. To enable a deeper discussion on the actions within the Plan, workshops on its implementation are organised back-to-back to Pressure meetings, where the feedback from the workshops is considered and appropriate decisions on further work are made,

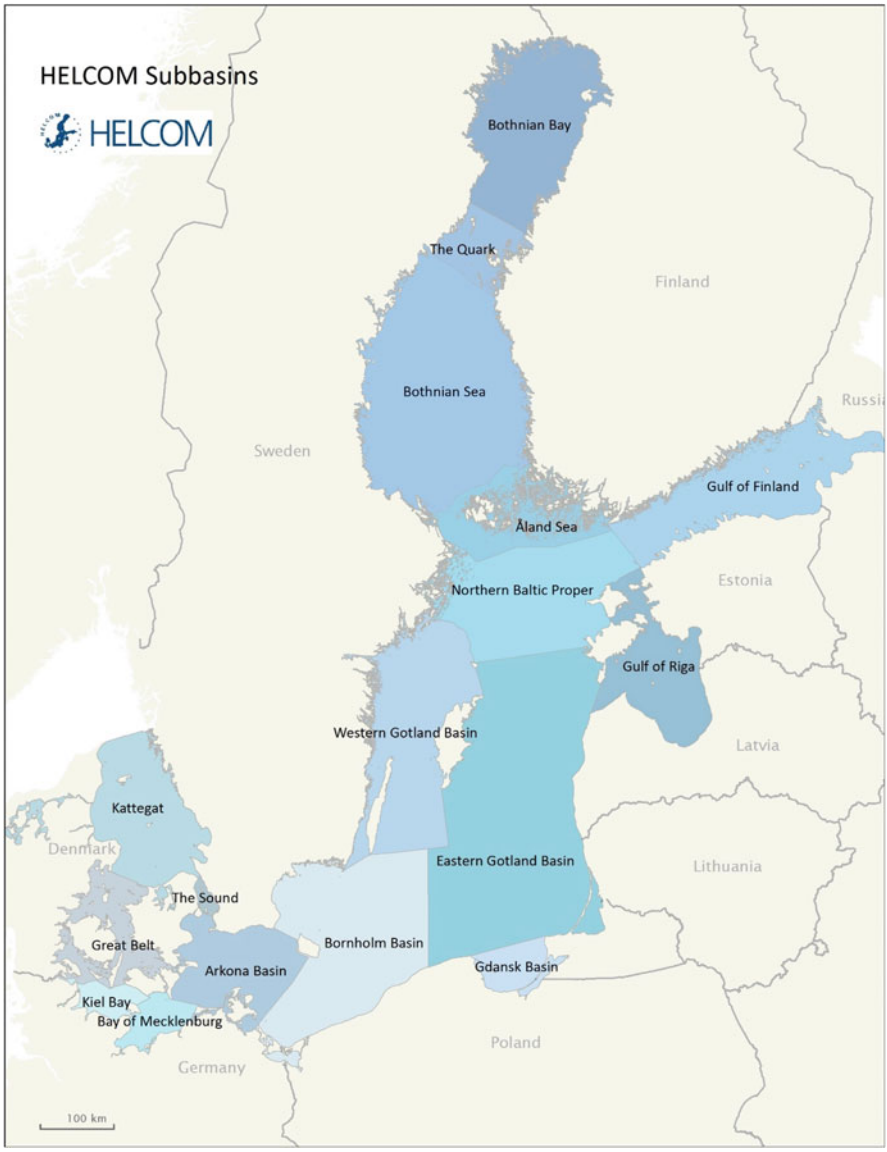

Fig. 1 Map of the HELCOM subbasins 2018. Division of the Baltic Sea into 17 subbasins as in the HELCOM Monitoring and Assessment Strategy

which will eventually be agreed at meetings of the Heads of Delegation. A summary of the latest status of the implementation of the Action Plan is available in the HELCOM website [22] and regularly updated.

Crucial is the role of the nationally nominated experts on marine litter on the implementation of the Action Plan. All HELCOM countries are part of the network

established in 2015, which is also open to HELCOM Observers. On this occasion, these Observers are Coalition Clean Baltic (CCB), European Federation of National Associations of Water Services (EurEau), Municipalities for Sustainable Seas (KIMO International), European Association for Plastics Manufacturers (PlasticsEurope) and Polish Association for Plastics Manufacturers (PlasticsEurope Polska), World Wide Fund for Nature Finland (WWF Finland), World Wide Fund for Nature Poland (WWF Poland) and Waste Free Oceans (WFO).

The follow-up of the implementation of the Action Plan concerns those actions agreed to be implemented regionally (R), the so-called collective actions. They are a total of 30 actions (Table 2), 15 of which aim at addressing land-based sources of marine litter (RL), 12 sea-based sources (RS) and 3 education and outreach on marine litter (RE).

As it happens with the indicators' work, individual actions in the Action Plan are conducted thanks to the lead of a country with the support of the whole network of experts. The figure below represents the status of leadership of the regional actions (Fig. 2). From the 30 actions in the Action Plan, 11 of them do not have a lead. Please note that there are cases when an action can have both a lead and a colead, or more than one lead, and so on. This may explain the difference in progress made depending on the actions: work is ongoing on 19 actions, whereas it has not been initiated for 11 of them. Of course, this is an ongoing process, and work on three actions has been initiated since the last Pressure meeting.

Coming to the details of the progress done so far in the implementation of the Action Plan since its adoption in 2015, actions have advanced mainly through three different approaches: (1) questionnaires among HELCOM countries to compile national available information and subsequent analysis of the feedback received; (2) national reports and projects contributing the different actions in the Action Plan; and (3) organisation of specific events.

Eight questionnaires have been used as mechanism to compile available data as well as information on national practices. One questionnaire was circulated to compile background information for drafting HELCOM guidelines on best practice on waste management to prevent waste turn into marine litter (action RL3) alongside with addressing cleaning and collection systems to prevent litter from land entering the aquatic environment (action RL2) and marine litter references in waste management plans (action RL1). Countries are currently providing their input to the questionnaire, and it is envisaged that in the upcoming months, a report summarising the feedback received will be available.

Another questionnaire was also used to prepare a study addressing the illegal discharge of onboard generated waste conducted in 2016 (actions RS2 and RS3). On this occasion the questionnaire was distributed to both HELCOM and OSPAR countries to collect knowledge regarding the regime of control and inspections of MARPOL Annex V infringements in the respective countries. This was accompanied by a review of the existing legal framework as well as relevant literature. A supporting report "Analysis of penalties and fines issued by OSPAR and HELCOM Contracting Parties for waste disposal offences at sea" was the result of such work [23].

Table 2 List of regional actions as contained in the HELCOM Action Plan on marine litter

CODE OF ACTION	REGIONAL ACTION	FURTHER SPECIFICATION
RL1	Prepare and agree on HELCOM guidelines on marine litter references to be included in national and local waste prevention and waste management plans, i.a. an element highlighting the impacts of marine litter.	Guidelines by 2017
RL2	Provide HELCOM guidelines on best practice routines with regard to cleaning and collection systems to prevent litter from land entering the aquatic environment.	Guidelines by 2017
RL3	Share best practice on waste management in order to identify and address loopholes that makes waste turn into marine litter, including the issue of landfills, regulations and enforcement.	_
RL4	Improvement of stormwater management in order to prevent litter, including microlitter, to enter the marine environment from heavy weather events.	By 2018 at the latest HELCOM has compiled information to give guidance on improvements of stormwater management on a local level to prevent and reduce stormwater related waste (including micro litter) entering the marine environment, taking into consideration similar action within OSPAR. If appropriate according to findings of the activity and other relevant information, amend HELCOM Recommendation 28E/5 on municipal wastewater treatment.
RL5	Establish a dialogue and negotiate on solutions with business and industry to (i) develop design improvements that reduce the negative impacts of products entering the marine environment, and (ii) reduce over- packaging and promote wise packaging	Initiatives taken by the private sector.
RL6	Establish an overview of the importance of the different sources of primary and secondary microplastics. Evaluate products and processes that include both primary and secondary micro plastics, such as fibres from clothing, assess if they are covered or not by legislation, and act, if appropriate, to influence the legal framework, or identify other necessary measures.	By 2017 an overview on what products and processes contribute to the input of micro plastics to the Baltic Sea, taking into account similar action within OSPAR. By 2018 existing legislation is assessed and necessary measures identified together with relevant stakeholders.
RL7	Compilation of available techniques as well as research and develop additional techniques in waste water treatment plants to prevent micro particles entering the marine environment.	By 2018 HELCOM has compiled information and prepared a report on micro particles removal in waste water treatment plants taking into account similar action within OSPAR. If appropriate according to findings of the search and other relevant information, amend HELCOM Recommendation 28E/5 on municipal wastewater treatment.
RL8	Assess the importance of the contribution of upstream waste flows to the marine environment and, if needed, identify suitable actions.	By 2017 an assessment of the importance of sewage related waste coming from the upstream waste flow is produced. By 2018 share assessment with River and River Basin Commissions and identify measures including the implementation of related regulations; missing elements are identified and guidelines for improvement are presented.
RL9	Compile information on the prevalence and sources of expanded polystyrene (EPS) in the marine environment and engage with industry to make proposals for alternative solutions (e.g. use of other materials, establishment of deposits, return and restoration systems, overpackaging reduction).	By 2017 an overview of the most significant sources of EPS ending up in the marine environment is produced, in cooperation with OSPAR. Make recommendations to the Contracting Parties on voluntary agreements with the industry on changes in product design and applying best practices when handling EPS by 2019.

(continued)

Table 2 (continued)

RL10	Define and implement appropriate instruments and incentives to reduce the use of plastic bags, including the illustration of the associated costs and environmental impacts (e.g. establishment of levies, deposit fees, taxes or bans on plastic bags). Support regional coordination in the Baltic Sea of the implementation of the future revised Directive 94/62/EC on packaging and packaging waste to reduce the consumption of lightweight plastic carrier bags, for HELCOM Contracting Parties being EU members.	By 2018 HELCOM Contracting Parties start to coordinate and inform each other about consumption of plastic bags on an annual basis. By 2019 establish a reduction target of plastic bags, taking into account the measures which are implemented nationally.
RL11	Cooperate on the establishment and/or further development of deposit refund systems for bottles, containers and cans (e.g. glass, plastics and aluminium) in the HELCOM Contracting Parties in accordance with national law as appropriate. Investigate and strive for bilateral and multilateral solutions between the countries for establishment of such systems in relation to passenger ships.	CPs informing in 2017 on the status/plans regarding the deposit refund systems, including on possible solutions regarding passenger ships.
RL12	Encourage, based on existing labels such as the EU Ecolabel and the Nordic Ecolabel, exchange with international environmental certification schemes for information and inclusion of the management and prevention of marine litter in their lists of criteria.	By 2016 initiate an activity on what certification schemes could be addressed, which existing criteria could be promoted for potential inclusion in international certification systems together with ways and means how to help approving those.
RL13	HELCOM Contracting Parties to seek cooperation with the River and River Basin Commissions, as appropriate, in order to include impacts of litter on the marine environment from riverine inputs, taking into account activities in the context of the implementation of the Water Framework Directive (WFD) and the Bathing Water Directive, and beyond, when applicable. This cooperation should include the exchange of experience on best practice to prevent litter entering into water systems, in line with action RL8.	HELCOM Contracting Parties will continue cooperation with River and River basin Commissions, as appropriate, in order to integrate measures addressing the reduction of littering in river basins followed up by appropriate information exchange on the implementation of measures.
RL14	Address landfills or dumpsites including historic ones which may eventually pose a risk to the marine environment due to factors such as coastal erosion and vicinity to rivers.	By 2020 a regional-wide map on landfills and dumpsites including historic ones which may eventually pose a risk to the marine environment is produced.
RL15	Establish an exchange platform for spreading experiences on good cleaning practices in beaches, including cleaning beaches actions by local communities, riverbanks, pelagic and surface sea areas, ports, marinas and inland waterways, in cooperation with relevant fora. Develop best practice on environmentally friendly technologies and methods for cleaning.	Coordinate with other RSCs in order to set up an exchange platform for spreading experiences on good cleaning practices in the different marine compartments and rivers.
RS1	Development of best practice on the disposal of old pleasure boats (i.e. intentional disposal of the boats at the ending of their lifetime in the sea and on shore).	Best practice developed by 2018
RS2	Develop best practice in relation to inspections for MARPOL Annex V, including harmonized management of data. Support regional coordination of IMO regulations in accordance with EU requirements for those HELCOM countries which are EU members.	Best practice developed in cooperation with Paris MoU by 2017

(continued)

Table 2 (continued)

RS3	Further work on implementation and harmonization of the no-special-fee system in ports of the Baltic Sea countries, addressing: * gaps in existing regulations, * enforcement and practices concerning shipping, * port reception facilities auditing to assess adequacy of garbage collection, * fair waste burden sharing between ports.	Evaluate the implementation of HELCOM Recommendation (28E-10), starting 2016
RS4	Implementation of the ISO standard (ISO 201070:2013) in relation to port reception facilities. Differentiate according to the size of the port. Promote the development of regional statistics on waste collected in ports based on existing information as far as possible.	Assess how many ports are operating according to ISO standards and to propose action as appropriate by 2017.
RS5	Promote and disseminate best practice in relation to all relevant aspects of waste management within the fishing sector (including e.g. waste management on board, waste management at harbors and operational losses/net cuttings).	By 2018, based on the OSPAR outcome, select best practices to be disseminated in the Baltic Sea.
RS6	Through a multinational project, such as the MARELITT Baltic project, together with the fishing industry and other stakeholders, develop and promote best practice in relation to ALDFG and derelict fishing gear and their removal.	Best Practice developed by 2017, the issues is promoted within HELCOM- EUSBSR cooperation
RS7	Compile information and elaborate guidelines on best practices to reduce the input of ALDFG from commercial and recreational fishing to the Baltic Sea taking into account geographical particularities; utilize UNEP RSC report and FAO on ALDFG as a starting point and focus on regional specifics	Guidelines developed by 2017 taking into account geographical particularities.
RS8	Identify the options to address key waste items from the fishing and aquaculture industry, which could contribute to marine litter, including deposit schemes and extended producer responsibility.	Late 2016 assess the use of OSPAR document and in consultation with the Baltic Sea Advisory Council consider and agree on the way forward to address key waste items from the fishing and aquaculture industries.
RS9	Investigate the use and prevalence of dolly ropes (bunches of polyethylene threads used to protect the cod end of demersal trawl nets from abrasions; synthetic fibre) in the areas of the Baltic Sea where they are used and consider the need to act.	Consider the outcome of the study on the impact of dolly ropes currently under development by the Netherlands. Baltic Sea Advisory Council is to be invited to be involved in this activity.
RS10	Mapping of snagging sites or historic dumping grounds and a risk assessment for identifying where accumulation of ghost nets pose a threat to the environment and should be removed.	As part of the assessment to be developed by HELCOM SUBMERGED by 2016. Mapping by 2017. Risk assessment
RS11	Based on the risk assessment conducted in RS10 and identification of accumulation areas, initiate removal of ghost nets and their safe management on land.	The aim is to increase the removal and disposal of the nets, and that statistics are available to confirm the increasing trend.
RS12	Enter into the partnership with international and regional organizations (e.g. KIMO, NABU, OSPAR Commission) as well as port authorities, to encourage implementation of passive Fishing for Litter schemes, to collect litter caught in fishing nets during normal fishing activities.	Increasing trends in the number of vessels from the fishing sector involved in the schemes.

(continued)

Table 2 (continued)

RE1	To prepare information sheets to assist Contracting Parties in developing material for education programs, especially for professional seafarers including fishermen, highlighting the marine litter problem and including codes of practice in cooperation with relevant organisations including IMO.	Information sheets to be prepared by 2016
RE2	HELCOM website to be updated periodically based on the input from Contracting Parties on marine litter management activities.	2015 initial information uploaded (simplified BSAP follow up system)
RE3	Develop a communication strategy for this Regional Action Plan linked in a coherent way with national initiatives/actions. This will include linking the HELCOM website to relevant projects and initiatives.	2016

Actions addressing land-based sources are in green, sea-based sources in blue and education and outreach measures in yellow

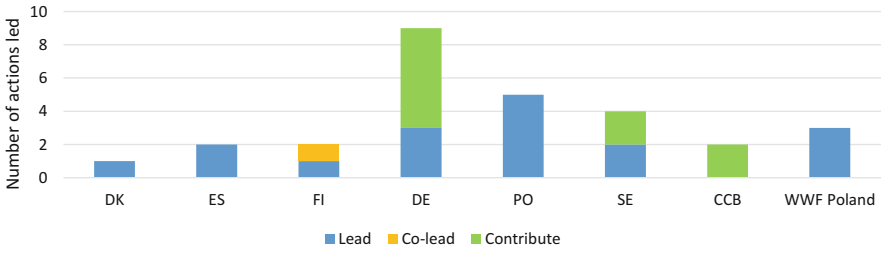

Fig. 2 Status of leadership of actions in the Action Plan by countries and observers

An "Analysis of the degree of the marine environment pollution by wastes flowing down the rivers to the sea, including sanitary waste" is the result of the feedback provided by countries through another questionnaire on the management of their sanitary waste (action RL8). It is envisaged to share the report with River and River Basin Commissions in the upcoming months.

One questionnaire was also used to gather knowledge on the prevalence and sources of expanded polystyrene (EPS) and XPS (extruded polystyrene) in the Baltic Sea and to suggest possible measures to reduce the environmental load of EPS and XPS in the Baltic Sea. The study which is currently being finalised will form the knowledge and decision-making basis for further work associated with action RL9 in the Action Plan.

To cooperate on the establishment and/or further development of deposit refund systems for bottles, containers and cans (e.g. glass, plastics and aluminium) in the HELCOM countries in accordance with national law as appropriate (action RL11), a survey was conducted. Its result indicated that currently functioning deposit refund systems for bottles, containers and cans are in place in Denmark, Estonia, Finland, Germany, Lithuania and Sweden. In Latvia, Poland and Russia, the system is not in place at that moment. The survey also indicated that there is no action regarding

bilateral and multilateral solutions between the countries for establishment of such systems in relation to passenger ships, which would affect, for example, passenger ships making the route Tallinn (Estonia)-Helsinki (Finland).

Again, one questionnaire was used to gather knowledge on whether landfills or dumpsites including historic ones may eventually pose a risk to the marine environment due to factors such as coastal erosion and vicinity to rivers (action RL14). The survey conducted in 2016, which was replied by all HELCOM countries except Germany, Lithuania and Russia, indicated that all landfills are under control in the region and cannot be considered as sources of marine litter.

The action aiming at producing a best practice model on disposal of end-of-life pleasure boats (ELBs) (action RS1) is currently being implemented. Most of the ELBs are made of fibre-reinforced plastic (FRP). FRP, when clean, can be reused and/or recycled to some level, but the material coming from ELBs is dirty and therefore challenging to reuse and/or recycle. Adding to the problem, most of the ELBs are treated with antifouling paints, which today contain copper and zinc. Many boats which are in the need of dismantling are old (from 1970s and onwards) and have been treated with organotin compounds, such as tributyltin (TBT), as the use of those was allowed in leisure boats until 1991, when it was banned in boats under the length of 25 m on the European level. As part of the best practice model development, information on the situation as it is now is being compiled through a questionnaire; the results of this exercise are to be available in the upcoming months.

The last questionnaire to mention is in relation to abandoned, lost and otherwise discarded fishing gear (ALDFG). Recently conducted, it had enabled the compilation of information on national activities on ALDFG thanks to the contribution of all HELCOM countries [24]. Based on this overview, a preliminary list of actions to serve the discussion on further regional actions on ALDFG in HELCOM has been drafted:

- To improve the management of the ALDFG once recovered from the sea. One country has a national regulation where marked gear is transferred to the owner if identified, whereas unmarked but suitable for further use gear is intended for sale and auctioned; all the remaining equipment is stored in the harbour areas. This could be explored to apply regionally.
- To consider the need to further work on the follow-up on the implementation of HELCOM Recommendation 28E/10 [3], on the application of the no-special-fee system to ship-generated wastes and marine litter caught in fishing nets in the Baltic Sea area.
- To further improve the reporting system on lost fishing gear (LFG) data, so that more knowledge of the amount of annual LFG in national waters is available.
- To gather more data on the amount of fishing gear lost and recovered in most of HELCOM countries. There are high expectations on the results of the MARELITT Baltic project – reducing the impact of marine litter in the form of derelict fishing gear in the Baltic Sea.
- To use the conclusions on a survey conducted in 50 Baltic fishing harbours on the adequacy of ports to receive, separately collect and sort the derelict fishing gear

collected from the sea as well as end-of-life fishing to improve the collection and sorting of fishing gear (FG) at ports [25]:

- More than half of the harbours surveyed organised waste management services at a reasonably good level.
- Fishing harbours in Germany and Poland have somewhat better general ability to organise waste management than those in Sweden[1] and Estonia.
- Almost half of the harbours do not have enough containers suitable for the separate collection of waste.
- FG is not separately collected in almost half of the fishing harbours but placed in the same container as other municipal wastes.
- In most cases, the harbour personnel are unaware of what happens next to separately collected FG.
- There are deficiencies in the provision of information to the harbour users, i.e. fishermen do not always know where and when end-of-life FG must be collected.
- No attention has been given to information and communications technology (ICT) opportunities for introducing the waste management rules and organisation of work at harbours (e.g. the harbour's website does not provide enough information).

- Other possible measures to improve the collection and sorting of FG at ports: end-of-life fishing gear collection organised and financed by fisheries associations and establishment of fishing for litter schemes in ports (based on national experience).
- To compile available information on recycling methods for retrieved fishing gear (MARELITT final) report envisaged in March 2019, as well as national experiences including the establishment of extended producer responsibility (EPR) schemes.
- There is knowledge available on best practices to reduce the amount of ALDFG, which may be analysed and further elaborated to implement action RS7 of the RAP on marine litter (ML), on the development of guidelines on best practices to reduce the input of ALDFG from commercial and recreational fishing to the Baltic Sea.
- To use available information to initiate the drafting process of the development of a report on best practices in relation to ALDFG and derelict fishing gear and their removal in fulfilment of action RS6 of the RAP on ML.
- In relation to the possibility of establish an EPR scheme for FG, it is important to follow up the EU process on the proposal for the European Directive on the reduction of the impact of certain plastic products on the environment [26][2] and on the revision of the EU Port Reception Facilities Directive [27], together with

[1]Please note that the survey does not cover the west coast of Sweden.

[2]The European Parliament and the Council of the European Union reached a provisional political agreement on the proposal on 19 December 2018.

national experiences on the topic that may contribute to advance on this issue in the region.
- To increase efforts to further advance on the mapping of snagging sites or historic dumping grounds and a risk assessment for identifying where accumulation of ghost nets poses a threat to the environment and should be removed as required by action RS10 in the RAP ML.
- Further work is needed to advance on removal of ghost nets where they have been identified as posing a threat to the environment which may only be possible to conduct once hotspots are identified.

Discussion on the further steps to approach the complex issue of ALDFG is to continue, but now we have a clearer picture of the situation in the Baltic Sea area.

It is not the purpose of this chapter to go through all the national reports contributing to the actions in the Action Plan, but it is worth mentioning that countries have informed about over 16 reports, projects or initiatives[3] which serve the purpose of specific actions in the Plan. Moreover, most of these projects target microplastics, from the identification of the importance of different sources of primary and secondary microplastics (action RL6) to possible techniques in wastewater treatment plants to prevent microparticles from entering the marine environment (action RL7). In addition, these actions will highly benefit from the outputs of the EU INTERREG Baltic Sea Region project FanpLESStic-sea – initiatives to remove microplastics before they enter the sea [28]. This project, which HELCOM is involved in, will produce (1) a model to map, understand and visualise microplastic pathways that will be applied to the partners' cities and/or regions; (2) piloting of new technology (a) for filtering out microplastics; (b) sustainable drainage solutions as means for removal of microplastics; and (c) to remove microplastics from storm water; (3) defining innovative governance frameworks and engaging a large range of players for the implementation of coordinated and cost-efficient measures resulting in locally adapted investment proposals/plans for each partner's region; and (4) dissemination of project results, including reports on barriers and ways forward, to increase institutional capacity on upstream and problem-targeted methods to remove microplastics. The FanpLESStic-sea project will run for 30 months (January 2019–June 2021).

The following two events can be pointed out as drivers of actions in the Plan: the HELCOM-INTERREG-Workshop on Marine Litter and Ecodesign held on 15 June 2018 (action RL5) and a German seminar on the prevention of and sanctions on illegal waste disposal from ships at sea (actions RS2 and RS3) held on 29–30 November 2018, both held in Berlin (Germany).

The aim of the workshop was to engage in a dialogue and enhance cooperation with and among designers, representatives of industry, research institutions, civil society organisations, national authorities and other stakeholders. It discussed how ecodesign principles, methods, tools, approaches and circular systems can be

[3] Additional information can be found as part of the follow-up process of the implementation of the Action Plan [22].

specified and applied to contribute to the reduction of marine litter in the Baltic Sea Area and which measures and framework conditions can support it. From the workshop evolved the "Principles for design reducing/preventing marine litter" [29] which were welcomed in the HELCOM framework and are to be further elaborated into HELCOM guidelines.

The German seminar was a follow-up of the German study addressing the illegal discharge of onboard generated waste conducted in 2016. The seminar provided the floor to discuss and exchange information on existing and best practices about the enforcement of international, regional and national law as well as better coordination of the involved bodies and actors.

Finally, there are some other actions which work has been conducted through other pathways than questionnaires or events, such as the action aiming at improving the storm water management to prevent litter, including microlitter, from entering the marine environment from heavy weather events (action RL4). On this occasion, discussion has been initiated on the need to amend HELCOM Recommendations on wastewater management to integrate provisions aimed at preventing the release of microlitter from wastewater treatment plants and urban and other storm waters into the marine environment. These are the four HELCOM Recommendations referred to:

- HELCOM Recommendation 18/4 on managing wetlands and freshwater ecosystems for retention of nutrients (1997) [30]
- HELCOM Recommendation 23/5 on reduction of discharges from urban areas by the proper management of storm water systems (2002) [31]
- HELCOM Recommendation 28E/5 on municipal wastewater treatment (2007) [32]
- HELCOM Recommendation 28E/6 on on-site wastewater treatment of single family homes, small businesses and settlements up to 300 person equivalents (P.E.) (2007) [33]

It is foreseen that this discussion continues once additional knowledge is available.

The action aiming at establishing an exchange platform for spreading experiences on good cleaning practices in beaches, including cleaning beaches actions by local communities, riverbanks, pelagic and surface sea areas, ports, marinas and inland waterways (action RL15), may be considered addressed by the international environmental campaign "Clean Beach" – 2018. This campaign is carried out in the frame of cooperation between Saint Petersburg (Russia) and cities of the Baltic region such as Tallinn (Estonia), Helsinki and Turku (Finland) with the aim of developing youth cooperation in the field of environmental protection, improving the ecological culture of citizens and developing environmental volunteer movement.

One important image to keep in mind would be the one from the Marine Litter Stakeholder Workshop [34] held in Helsinki in 2016, where over 90 representatives of governments, industry, municipalities, researchers, financing instruments, nongovernmental organisations and consumers gathered for summarising their

Fig. 3 Participants to the Marine Litter Stakeholder Workshop (Helsinki, 2016)

views with regard to the Baltic situation, for finding better solutions through common discussions and for ensuring leadership for combating litter (Fig. 3). The spirit is still alive and is guiding our work on further implementation of the Action Plan.

5 HELCOM's Role Outside the Baltic Sea Region

5.1 United Nations

HELCOM is following with attention and actively contributing to the work on marine litter conducted in the frame of the United Nations (UN): participating in relevant meetings, providing input to reports [35, 36] and spreading the word of UN campaigns, such as the most recent one, "Beat Plastic Pollution". Proving its commitment on marine litter issues at the international level, HELCOM recently joined a collective statement by the Regional Seas Conventions and Programmes to the second meeting of the UN Ad Hoc Open-Ended Expert Group on Marine Litter and Microplastics [37].

It is also worth recalling that the United Nations Environment Assembly (UNEA) of the United Nations Environment Programme (UNEP), Resolution on Marine litter and Microplastics (UNEP/EA.3/Res.7) [38] and the HELCOM Action Plan share the same objective of "by 2025, prevent and significantly reduce marine pollution of all

kinds, in particular from land-based activities, including marine debris and nutrient pollution".

5.2 European Regional Seas Conventions

There is an ongoing informal cooperation between OSPAR Commission (Oslo and Paris Conventions – Protecting and conserving the North-East Atlantic and its resources), United Nations Environmental Programme for the Assessment and Control of Marine and Coastal Pollution in the Mediterranean Region (UNEP-MEDPOL), HELCOM and countries belonging to both Conventions which meet annually since 2014 aiming at identifying possibilities for cooperation within the implementation process of the respective Action Plans on Marine Litter. The idea of these informal meetings is to avoid duplication of efforts, exchange of information and share outputs that can be useful for all. As part of this process, the following common actions in the three Action Plans have been catalogued as priority actions for cooperation:

- Implementation of MARPOL Annex V/waste management in ports
- Waste prevention and management: (1) general perspective, (2) single-use plastic bags, (3) primary microplastics and (4) other key waste items
- Passive fishing for litter activities
- Accumulation areas/hotspots of marine litter (including ghost nets)
- Clean-up campaigns (national, international)
- Public awareness and education activities/citizen science and data

In the last 2 years, representatives from the European Commission also attended these meetings, providing also the link to the EU perspective.

5.3 European Union

In relation to HELCOM contribution to ongoing EU processes, HELCOM work on marine litter is regularly shared with the MSFD Technical Group on Marine Litter (TG Marine Litter), not only through the participation in their meetings and provision of input to the reports TG Marine Litter produces but also ensuring that HELCOM processes are aligned with the EU ones. In this regard, the case of the EU Strategy for Plastics [39] is to be pointed out. The Strategy adopted in January 2018, among other issues, envisages reduction options for single-use plastic items. Specifically, Annex II of the Strategy contains "List of measures recommended to national authorities and industry" where key measures encouraged for regional authorities to conduct are also listed. The measures which national and regional authorities are encouraged to conduct are grouped into four categories:

– Key measures to improve the economics and quality of plastics recycling
– Key measures to curb plastic waste and littering
– Key measures to drive investments and innovation towards circular solutions
– Key measures to harness global action

An analysis of the linkages between the actions in the Action Plan and additional HELCOM activities and these encouraged actions to regional authorities was made [40]. The analysis went further and analysed the proposal for a Directive on the reduction of the impact of certain plastic products on the environment [41] (together with the explanatory memorandum of the proposal) which once in force[4] shall apply to single-use plastic (SUP) products listed in the Annex [42] to the proposal and to fishing gear containing plastic. The analysis conducted indicated that EU and HELCOM streams of work are aligned.

6 Next Critical Date: 2021

2021 is a very important date in the HELCOM calendar, with the Baltic Sea Action Plan (BSAP) to be updated then. Why is that important? The BSAP signed in 2007 has guided all HELCOM work towards the ambitious goal of achieving a good environmental status of the Baltic Sea by 2021. It is time for an update to adjust actions based on the newest scientific knowledge so that HELCOM's strategic goals and ecological objectives can be reached and relevant marine and water targets of 2030 Agenda for Sustainable Development can be met in the Baltic Sea. The updated BSAP will include the existing commitments that may not be fulfilled by 2021 and also address new issues on the basis of the commitments made in the 2018 Ministerial Declaration and further deliberations during the BSAP update process.

Proposals on new HELCOM actions for the updated BSAP will primarily build on results of the analysis of sufficiency of existing measures that will be carried out through a similar approach across topics and coordinated through the Platform on Sufficiency of Measures (SOM Platform) and the HELCOM-led and EU co-funded ACTION project. It is envisaged that one of these topics is marine litter. The planned work will require, among others, collection of information on existing measures to reduce marine litter in the Baltic Sea region. Information on the effectiveness of existing measures and syntheses on the potential effect of new measures will also be prepared to support the analyses. The syntheses are aimed at being ready by the end of 2019 and the analyses of sufficiency of measures by mid-2020.

In 2020 HELCOM workshops are planned to be arranged to discuss the outcome of the analysis and use it as a basis for identifying the need to strengthen existing

[4]The proposal was adopted by the European Parliament in October 2018. The envisaged process now is that the Parliament enters into negotiations with Council when EU ministers will have set their own position on the report containing the proposal.

HELCOM actions or to agree on new HELCOM actions to be included in the updated BSAP.

All these processes will be extremely linked to the revision of the Action Plan which is envisaged to be conducted also in 2021.

Despite plastic pollution only being addressed more recently with full attention, HELCOM can draw from over 40 years of experience in tackling pollution in general. The way for the Baltic Sea free from litter and plastics has been durably set.

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Combating Marine Plastics: The Role of Finance and Technical Assistance by Development Finance Institutions

Georg Caspary

Contents

Abstract Combating the marine plastics problem at scale requires operational support to the main marine plastics source countries. Development Finance Institutions (DFIs) are uniquely placed to do this, through their extensive experience in helping developing and emerging economies address a range of development challenges.

This article will lay out the role DFIs may play in this regard. It is structured as follows:

– First, Sect. 1 provides the background, laying out what DFIs are and what they do.

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– Secondly, Sect. 2 indicates the range of work DFIs may engage in on marine plastics, covering both finance and technical assistance.
– Next, Sect. 3 does the same for private finance and technical assistance.
– Further, Sect. 4 discusses the possible way forward for DFI involvement in addressing marine plastics; covering the need for DFIs to mainstream marine plastics work; developing synergetic approaches toward financing and technical assistance between DFIs; and establishing collaboration with other bodies.
– Finally, Sect. 5 concludes by pointing to the importance of country ownership of efforts to stem marine plastics pollution and integration with other issue areas.

Keywords Finance, Plastics, Technical assistance, Waste

1 Background

1.1 What Are DFIs?

Development Finance Institutions (DFIs) provide risk capital for economic development projects. They are often established by governments to provide funds to projects that would otherwise not be able to get funds from commercial lenders [1, 2].

There are two major types of DFIs ("Although foreign aid can be classified and decomposed along several dimensions, bilateral aid and multilateral aid seem two major components. . .", as stated in 2003 [3], p. 96): multilateral DFIs are mostly the World Bank Group and regional development banks such as the Asian or African Development Bank, and bilateral DFIs are usually financial institutions set up as the vehicle to channel individual industrialized countries' foreign assistance. The DFI landscape has recently become more complex, with additions including emerging bilateral DFIs (notably by large emerging economies [4]), as well as the Asian Infrastructure Bank and the BRICS[1] Bank.

This chapter argues that DFIs are significant for addressing the marine plastics problem because much of the fight about marine plastics will be major investments that DFIs will have to make notably in managing plastic waste. In the long run, the overall capital needs associated with managing plastic waste are of course so large that much of the capital will have to come from the private sector; but DFIs are key to establishing the initial policies and institutions [5], for which they arguably provide the only financing available, and initial infrastructure, where they de-risk

[1]The term BRICS is frequently used to describe the group of largest developing or transition economies that are or are likely to become key economic and strategic partners for OECD countries in the coming years: Brazil, Russia, Indian, China, and South Africa.

investments in frontier technologies or frontier markets for eventual private sector involvement [6].

1.2 What Do DFIs Do

DFIs provide assistance to developing countries in a range of key physical infrastructure (energy, transport, water, waste) and social infrastructure (education, health) sectors. In this context, the role of DFIs in the fight against marine plastics is mostly about helping developing countries establish integrated solid waste management systems (ISWM) through establishing relevant policy and institutional frameworks and providing investments. Integrated solid waste management, as opposed to traditional solid waste management (SWM), refers to "the strategic approach to sustainable management of solid wastes covering all sources and all aspects, covering generation, segregation, transfer, sorting, treatment, recovery and disposal in an integrated manner, with an emphasis on maximizing resource use efficiency" [7].

ISWM with a specific marine plastics focus means focusing an institution's ISWM work on key source countries of marine plastics [8]. These source countries are mostly in an ongoing "assistance dialogue" with DFIs. A number of key marine plastics source countries are becoming increasingly concerned about marine plastics and have engaged with key DFIs on how to address the problem (e.g., Indonesia has long been working with the World Bank to establish complex assistance programs in this area, given the length of its coastline, problems in its current SWM systems, the resulting amount of plastics "leakage" into its waters, and the impact on Indonesian fisheries and tourism).

Two interrelated principles are at heart of the ISWM concept. First, the "waste hierarchy" is widely accepted among proponents of ISWM. It suggests prioritizing the four mentioned types of waste diversion (in the order of priority mentioned) over the three types of waste disposal (in the order of priority mentioned) (Fig. 1).

Secondly, ISWM uses the "waste value chain" approach illustrated below, which indicates the "path" of a plastic goods from when it is engineered to the very last chance at capturing it before it enters the ocean. At its heart, this approach suggests prioritizing earlier interventions over later ones (Fig. 2).

The assistance DFIs provide to developing countries can be categorized into two types: finance and technical assistance (TA). Both can come to bear in their emerging work on combatting marine plastics; we will discuss both categories here separately for the case of DFIs that mostly serve sovereign (government) and private (corporate) clients. Both exist at the multilateral (i.e., owned by multiple governments) or bilateral (i.e., owned by one government) level. For both sovereign and private DFIs, the next sections will discuss the finance and TA they can provide.

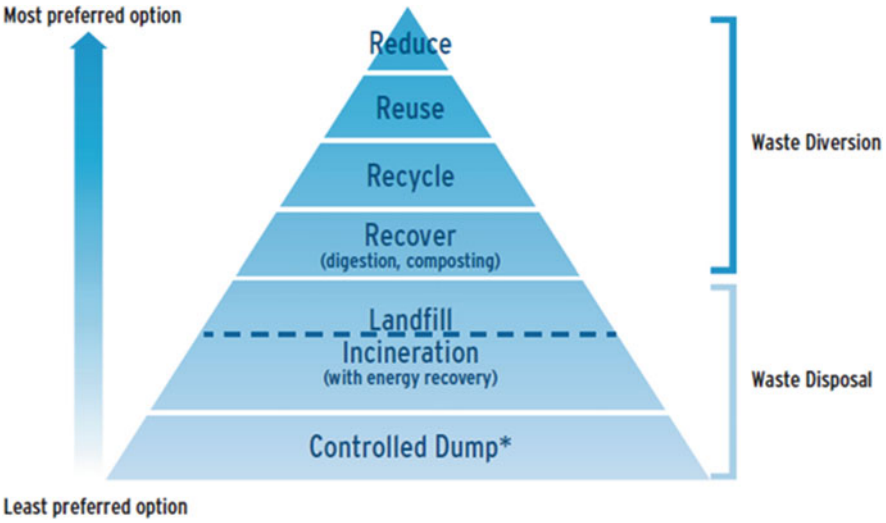

Fig. 1 The waste hierarchy. *Source*: [9]

2 Multilateral DFI Work on Marine Plastics in Sovereign Finance and Technical Assistance

2.1 Sovereign Finance

Multilateral DFIs comprise the World Bank as a global DFI; and regional multilateral banks focused on a particular region (e.g., the Asian or African Development Banks). The working structures of these institutions are similar; and they regularly collaborate in fora like the Multilateral Finance Institutions Working Group on the Environment (MFI-WGE).

Bilateral DFIs are mostly OECD country institutions in charge of disbursing that country's development aid; some emerging economies have now also established bilateral DFIs. Most DFIs coordinate their work in the OECD Development Assistance Committee (OECD-DAC) [11, 12].

Sovereign DFIs provide both policy-focused and investment-focused finance.

Policy-focused finance for ISWM helps with the design of polices (legal frameworks, laws, circulars, technical guidelines) to improve waste management systems and expedite a country's transition to circularity. Concretely, this could include fiscal incentives such as plastic pollution taxes. Policy-focused finance is usually disbursed by the DFI against the client country's concrete actions for which the policy-focused finance was agreed – e.g., promulgations of the relevant regulations.

Investment finance would help with the building of ISWM-related infrastructure such as waste collectors, incinerators, or treatment facilities. Investment finance is usually disbursed as an input prior to procurement of the relevant capital goods by the client country.

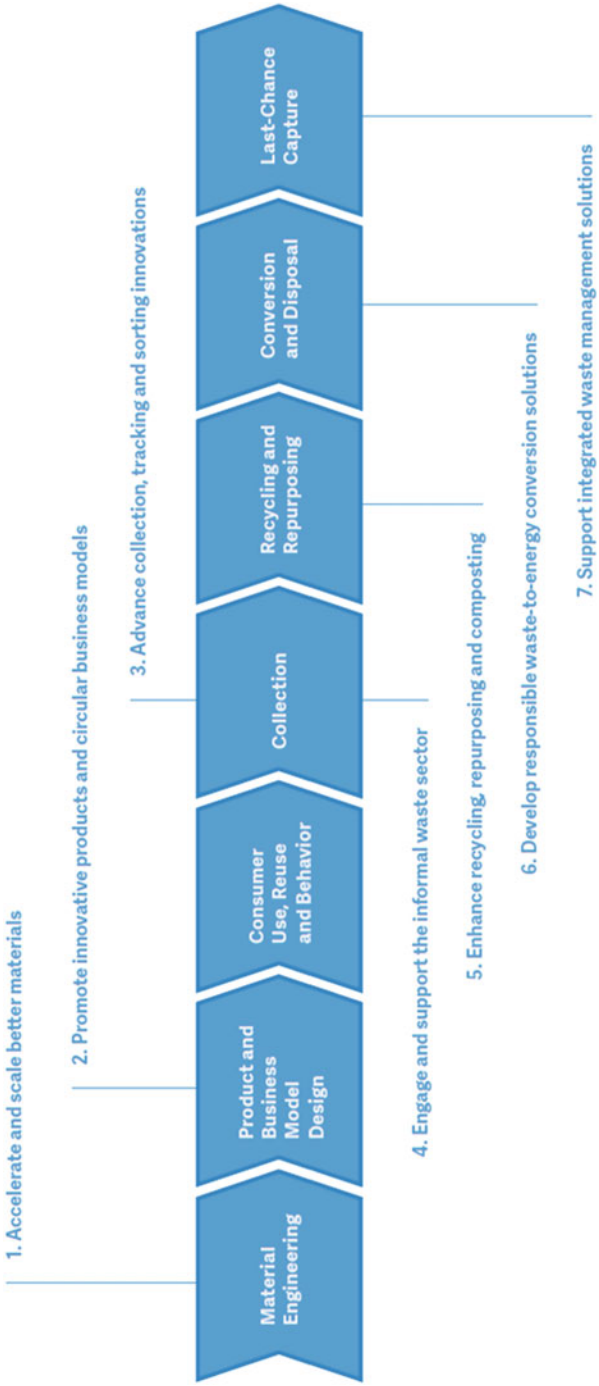

Fig. 2 The plastic waste value chain. *Source*: [10]

Apart from the core areas, many DFIs have developed specialized programs around ways of disbursing considered conducive to sovereign development finance. One key category in this respect is the so-called results-based financing. It supports client governments' own budgets and disburses when the relevant policies have been established and investments have been made (with a certain maximum amount up front, e.g., 25% in the case of the World Bank's "Program for Results") [13].

When deciding where to start with their assistance in trying to address the massive ISWM challenge in marine plastics source countries, some sovereign DFIs have turned to an internal portfolio review. This means, firstly, to identify the ISWM interventions undertaken by the institution over the years and analyze whether any marine plastics foci were so far present in these interventions. Secondly, it means developing a framework for integrating issues in ISWM to the DFI's projects and programs, including where ISWM interventions can most successfully be linked to local solid waste management challenges (i.e., classic "public service/infrastructure" investments in solid waste) and to global waste management issues and their associated emerging financial assistance based on the "global public goods" argument for clean oceans (see, e.g., [14–17]).

At the heart of this is, of course, the ability to successfully create financial arguments for marine plastics-focused ISWM interventions. Key among these, in turns, is that over three billion people depend on marine and coastal biodiversity for their livelihoods and that the market value of marine and coastal resources and industries is estimated at EUR 2,600 billion per year, so about 5% of global GDP [18].

Results-Based Financing in the Solid Waste Management Sector: Lessons from World Bank Operations

The World Bank has employed results-based financing (RBF) in many countries, including in the waste management sector. Several recent publications attempt to distill lessons from this work: RBF is more efficient when associated with other instruments such as infrastructure investment, policy reform, and technical assistance. When an RBF scheme is designed as a payment mechanism for SWM, the payment should fairly compensate the service received; however, if it is for individual noncommercial behavior change, the payment should be linked to the value of the outcome of the desired behavior change. RBF must be designed with a focus on a set of desired results, allowing the service providers to decide what service delivery model would best achieve those results. Monitoring and independent verification are key in a RBF scheme (after all, disbursements are made against verifiable progress). Balancing simplicity and meaningfulness in the design of the verification process is often a practical necessity when implementing RBF in the SWM sector. Addressing solid waste challenges often involves fundamental changes in behavior that can take time to establish. Hence, setting realistic targets is important in order to keep stakeholders motivated.

2.2 Sovereign Technical Assistance

Technical assistance (TA) has traditionally meant the transfer from a knowledge-rich North to a knowledge-poor South. It has recently been superseded to some extent by terminology considered to represent a more cooperative and dialogic conception (first "Technology Cooperation," "Joint Knowledge Management and Innovation Systems") [19].

At the heart of TA in the ISWM/marine plastics context is support to analytical work by sovereign DFIs to help client countries understand the sources, concentrations, and impacts and develop cost-effective abatement or cleanup options.

More ambitious TA programs would also support innovation around products and business models to combat marine plastics. This could be based on existing in-house Innovation and Entrepreneurship Programs in DFIs, such as the World Bank's InfoDev program [20], which already has an (so far mostly climate-focused) environmental technology window.

Finally, actionable behavioral science research ISWM for marine plastics holds much promise. For example, policies designed to encourage people to produce less waste or recycle more exist but need to be refined and adapted to specific country circumstances [21]. The World Bank's own behavioral science group is well placed to initiate this work.

Emerging Marine Plastics Funds in DFIs

DFI work on combatting marine plastics is not focused on single interventions. Several DFIS have recently initiated funds that provide a strategic set of complementary approaches. One example of this is the emerging marine plastics funds in DFIs.

For instance, the World Bank's "PROBLUE" fund is a multi-donor trust fund that aims to tackle marine pollution (including plastics) while also improving fisheries governance and fostering the sustainable growth of traditional and new oceanic activities [22]. On marine plastics, it aims to curb both nonpoint sources (agriculture, stormwater runoff) and point sources such as wastewater, solid waste, and lost fishing gear. Its interventions will aim to both stem the flow of plastics and waste to the ocean from land-based sources (mainly by improving waste management in coastal areas and along river basis) and marine sources (improving waste management in fishing activities, shipping, cruising).

Similarly, the European Investment Bank (EIB), German Kreditanstalt für Wiederaufbau (KfW), and Agence Francaise de Developpement (AFD) have jointly launched a 2-billion Euros initiative (Clean Oceans Initiative) for long-term financing for projects aiming at reducing marine litter, especially plastics, as well as untreated wastewater discharge, with a view to crowding in private sector investment [23].

(continued)

These three partner institutions will combine their expertise and experience to support the development and implementation of viable projects in this sector. The Clean Oceans Initiative will also provide innovative financing structures catering for the needs of private enterprises of varying size, including microenterprises, and for research and innovation projects. The Clean Oceans Initiative is global in nature but will focus particularly on operations in riverine and coastal areas in developing countries in Asia, Africa, and the Middle East, since 90% of plastic waste enters the oceans through ten major river systems located in Africa and Asia [24], where access to regular waste collection and controlled waste disposal often lacks.

The Clean Oceans Initiative will notably target the following sectors:

- Collection, pretreatment, and recycling of waste and particularly plastics collected on land, from rivers, and from the sea
- Improved waste management in ports and harbors to support the reduction of marine littering from ships and transport on water
- Support to plastic prevention measures, market development for recycling plastics and other materials, and public awareness building
- Support to the implementation of wastewater treatment plants that enable reduction in the discharge of plastics and other pollutants to rivers and oceans

3 DFI Support for Private Efforts on Marine Plastics

Private sector DFIs comprise, at the multilateral level, notably the International Finance Corporation (private sector "wing" of the World Bank); associated private sector-focused institutions in the multilateral regional development banks; and a range of regional DFIs such as the Deutsche Investitions- und Entwicklungsgesellschaft (DEG) in Germany.

3.1 DFI Support for Private Finance

The purpose of these institutions is to provide a range of financial products and expertise across various sectors in emerging markets to support the private sector and enable liquidity and risk sharing. Financing instruments employed comprise equity/quasi equity; loans (particularly long-term loans); risk management tools; and to a lesser extent asset management.

These institutions' investments in the SWM sector have tended to be less than in other sectors. The investment approach has mostly focused on promoting development of waste industry in emerging markets, helping reduce costs, and allowing the industry to become competitive.

Some of the private sector-focused DFIs have explicitly include support of ISWM in their mandate, including [25]:

- Leveraging existing formal and informal sectors for collection and recycling, to maximize poverty and social impacts and improve health and safety
- Encouraging low-cost, technically viable, and climate favorable waste collection and disposal solutions with energy recovery
- Supporting upstream industry/populations to adopt "3Rs" – reuse, reduce, and recycle
- Accessing concessional finance to enable waste projects in lower-income countries (LICs) where full cost recovery is not yet possible due to consumers' inability to pay or insufficient regulatory frameworks

3.2 DFI Support for Private Sector-Related Technical Assistance

Technical assistance provided by these DFIs tends to focus on helping governments look into involving the private sector to address waste issues by accessing private finance or expertise. This mostly happens through facilitating public-private partnerships (PPPs) in the SWM space.

DFIs provide transaction advice on PPPs to national and municipal governments in emerging markets to implement sustainable PPPs that improve living standards and promote long-term economic growth. Governments draw from the DFIs' experience in public financing and project finance to pave the way for private sector interventions. In the initial stage, this may include assessing the feasibility of private sector intervention, including the establishment of an enabling policy framework. Once the government has chosen to go the PPP route, the TA will include advising governments on designing and implementing it, and/or the identification of possible interventions at various stages of the waste management chain (e.g., arranging management concessions), and/or developing pilots for new models and innovation. It may also include components for extending access to waste management services to currently underserved parts of the population. Overall, the involvement by the DFIs strives to balance the requirements of private sector partners with investors with public-policy considerations and community needs (Table 1).

4 The Way Forward

The way forward for DFIs effectively supporting the fight against marine litter will include mainstreaming of such efforts in and among DFIs; collaborative approaches among DFIs; and collaboration with other bodies.

Table 1 Role of key actors in waste PPPs

Actor	Role
Private sector DFI	*Financing:* – Capital – At times also local currency facilities; guarantees and structured financial products
	Technical assistance: – Structuring sustainable agreements – "Balanced deals" – Attention to downside – Financially, economically, politically sustainable structures
Government (i.e., host government of the project)	*Financial support:* – Assets – In-kind contributions – Funding – Subsidy
	Political support: – Legal and regulatory frameworks
Private sector	– Financing – Management expertise – Technical expertise

Source: [26]

4.1 Mainstreaming

4.1.1 Mainstreaming Inside DFIs

Marine plastics-related efforts have to become mainstream in DFIs to become effective. In the past multilateral DFIs usually had separate social and environmental departments or even separate departments for social and environmental assessments [27, 28]. Work on SWM or even ISWM was included among DFIs' mandate, but often not by a dedicated team (usually as part of the urban infrastructure team). Even where a DFI has dedicated SWM/ISWM specialists, they tend to focus on it as a service/infrastructure issue, neglecting the environmental aspect. In how much this will change in response to the marine plastics challenge will depend in part on how strong the evidence of economic impact of marine plastics on client countries becomes, so that an economic and/or financial case to be made for investment in infrastructure can be made (so that countries are willing to ultimately take out financing, including loans, from DFIs to address the marine plastics issues).

Another determining factor will of course be interest group pressure on DFIs to engage on this issue. Notably multilateral DFIs have long been the targets of NGOs pushing for inclusion of social and environmental considerations even where no immediate investment case can be made [29].

4.1.2 Mainstreaming into Existing DFI Coordination Mechanisms

Especially multilateral DFIs have developed coordination mechanisms on social and environmental aspects of their work in which they coordinate and conduct informal peer review of each other's practices. While the multilateral working group on environment has been meeting regularly since the early 1990s [30], this process of coordination also gathered pace among bilateral financing institutions in the late 1990s (notably in the OECD Development Assistance Committee, where one subgroup – the Network on Development Co-operation and Environment – deals exclusively with questions of coordinating the environmental aspects of development cooperation).

4.2 Synergetic Approaches

Collaborative approaches between DFIs to combat marine plastics are already underway – as mentioned above in the example of a pooled fund between EIB, AFD, and KfW. Pooling may simply be about joining financial resources; or it may be about complementary geographic foci of different DFIs' operations.

DFIs may also become more strategic in such collaboration over time. One example of doing so is the complementary use of different DFIs' earlier disbursing versus later disbursing resources (since governments implementing measures against marine plastics would require start-up capital to do so, and cannot only wait for the disbursement of the World Bank's results-based financing later in the project life cycle). The World Bank has been looking into this approach, given the "late-disbursing nature" of its results-based financing mechanisms mentioned above. It has therefore talked to pioneers of early-disbursing assistance, such as the Dutch Government (whose green bonds would fit this description of early-disbursing financial instruments). The resulting interplay between late-disbursing World Bank lending; early-disbursing lending by other DFIs; and TA is shown in Fig. 3 and would constitute a comprehensive assistance package for a marine plastics source country.

4.3 Collaboration with Other Bodies

4.3.1 Global Intergovernmental Bodies

The global forum that has so far arguably been driving the marine plastics issue the most has been the G20, issuing communiqués on the issue at several G20 meetings. Moreover, the G20 has invited DFIs to actively "operationalize" its vision to reduce marine plastics (i.e., to provide the financing and TA with which the marine plastics envisaged by the G20 could be made a reality). This is of course in part driven by the

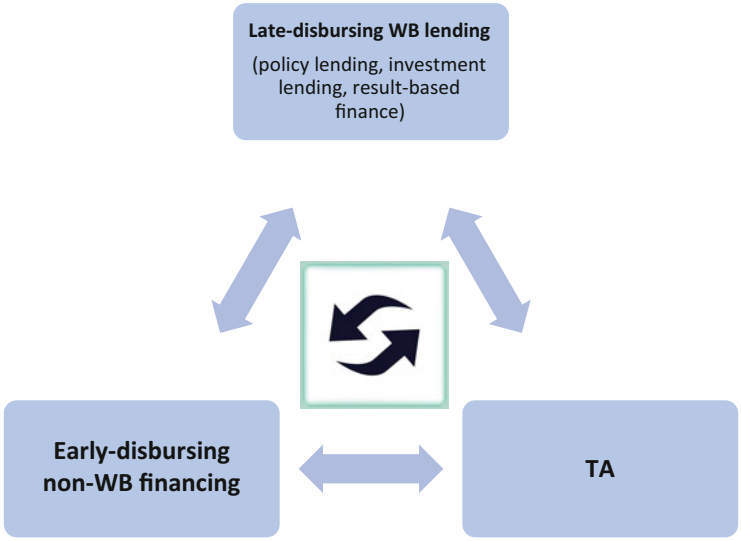

Fig. 3 Interplay between late-disbursing World Bank lending; early-disbursing lending by other DFIs; and TA. *Source*: [31]

fact that several of the G20 countries are among the key marine plastics source countries (China, India, Indonesia).

4.3.2 Regional Intergovernmental Bodies

Combatting marine plastics has, evidently, a strong regional dimension. "Leakage" from coasts into the ocean usually happens along coastal areas shared by several countries (e.g., southern China, Vietnam, Thailand, the Philippines, and Indonesia all contribute in this way to the South China Sea having become a "marine plastics hotspot"). Similarly, waterways serving as conduits for solid waste pollution are often shared between countries, with recent World Bank research having shown the amount of marine plastics being carried into the ocean in this way. Luckily, several of the major rivers in the world are already governed by intergovernmental institutions (e.g., the Nile Basin Initiative or the Mekong River Commission). These institutions often already organize themselves around issue-specific technical working groups, to which a working group on marine plastics could be added.

4.3.3 Industry Initiatives

One of the key institutions convening private industry sector actors interested in marine plastics reduction is Closed Loop Partners, convening key plastics producers, such as Coca-Cola, Unilever, Danone, or Nestlé, and retail/logistic companies such

as Walmart or Amazon that are heavily relying on plastics. In various events focused on the marine plastics issue, these companies have expressed that the key contribution they are hoping for from DFIs is work on regulations that can enable private sector investments in marine plastics reduction and risk management instruments to help de-risk related investments in certain markets.

A separate question exists on how to catalyze private venture activity with a view to marine plastics reduction (e.g., new types of plastics alternatives). This requires the classic publicly financed venture support infrastructure through incubators where new ideas are initiated and accelerators where they are being grown, combined with financing in the form of early stage seed capital, followed by access to risk capital.

For all of these ways in which DFIs can catalyze private sector involvement in marine plastics reduction, the regional focus should likely in the near term be on marine plastics source regions where the private sector is already largely willing to invest. Southeast Asia is likely a good fit in this respect, as are the middle-income countries in Latin America which have made significant recent reforms conducive to private investment (Chile, Peru, Colombia). Such a focus would fit well with the need to address the Pacific Gyre Garbage Patch.

5 Conclusion

Various challenges still exist for DFIs wanting to make the marine plastics agenda effective. We will highlight two here: the importance of country ownership and integration with other issue areas.

First, regarding the importance of country ownership, ultimately, the fight against marine plastics will be determined by how important the issue is to recipient countries (big marine plastics "source countries"). Most DFIs undertake ambitious programs only if the relevant partner country expresses the issue area as a priority. However, in cases where "source countries" do express this, DFIs will have a key role to play by deploying DFIs' finance and TA to get comprehensive marine plastics work underway in such countries.

Such an approach would fit well with the Paris Declaration on Aid Effectiveness. The Paris Declaration on Aid Effectiveness: Ownership, Harmonisation, Alignment, Results and Mutual Accountability is so far the main statement of resolve to improve the management and effectiveness of aid [32]. The Paris Declaration has instigated an international effort to put each developing country in the driver's seat for its range of externally financed policies and projects and for the country to coordinate these policies and projects effectively ("country ownership"; for detail on this concept, see [33]).

Second, regarding the integration with other issue areas, the success of scaling marine plastics work will hinge on consciousness of the global significance of the problem, evidence that it is in source countries' interest to act against it, and the establishment of links with other key development issues. The latter would include, for instance, integrating the marine plastics agenda into innovative ISWM

approaches that enjoy widespread support due to their developmental effects, such as:

- Community-based recycling that reduces the effects of uncontrolled plastics at the community level while creating jobs
- Assessments that indicate the health risks from marine plastics (e.g., be it through plastics making it into the food chain of communities heavily reliant on fish protein or through plastic creating immediate health risks by blocking storm or sanitary sewers, creating flooding or hygiene hazards, respectively)
- Ancillary benefits with other environmental agenda, such as when comprehensive ISWM programs also address the methane emissions from (mostly organic) waste

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The Current State of Law on Plastic Pollution in Mexico and a View Toward the Future

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Abstract Like many nations, Mexico is reviewing its waste management laws and policies in the face of growing evidence of the ubiquity, longevity, and negative effects of plastic waste in the environment, particularly in aquatic habitats. Split into two sections, this chapter will first explore the current Mexican legal framework and regulatory mechanisms regarding single-use plastics through its legal structure starting with the Constitution and continuing with self-executing international treaties, federal legislation, and related regulations. Although the analysis is not extended to the legal activities at state and municipality levels, it is noted that some states and municipalities have, as a result of international and local public pressure, enacted legislation regarding single-use plastics, generally targeting plastic bags and straws. In part two, a framework is proposed for a national legislative approach to address plastic pollution in the waterways of Mexico. Such an approach is intended to reconcile the differences across the states and provide a uniform regulatory structure, which draws upon the best practices to date from an international context. The proposed framework requires the creation of a hierarchy of plastics that identifies those that are beneficial to a healthy society and those that are detrimental. The resulting hierarchy suggests which plastics should, and should not, be in the stream of commerce. From there, the legal framework focuses on defining the composition of the polymers to be used for the chosen plastics to emphasize health, recyclability, and technical compatibility with closed loop systems where possible. Such uniformity is intended to enhance the value of the plastic waste to ensure products will in fact be recycled and that there will be a market for the material. To better protect Mexico's waterways and aquatic life, the legal mechanisms must ensure that the federal legal framework for pollution meets constitutional requirements and considers the entire life cycle of plastics from production to the end of its life.

Keywords Plastic pollution, Law on plastics, International regulation on plastics, Mexico

1 Introduction

Addressing the problem of plastic pollution in aquatic systems is a global challenge. Researchers have postulated that a third of all plastics ever produced are still in use [1]. The rest, i.e., the cumulative mass of primary and recycled plastic waste produced between 1950 and 2015, is deposited in landfills or the natural environment. The problem is growing as 8 million metric tons of plastic end up in the ocean each year [2]. Of that, roughly 80% comes from land-based sources [3]. A separate analysis published in *Nature Communications* suggested that between 1.1 and 2.4 million tons of plastics are conveyed to the ocean every year by rivers and streams [4]. At the same time, plastic production is growing exponentially. By 2050, the volume of plastic waste produced each year will nearly equal the total volume of

plastic waste produced from 1950 to 2017 [1]. That would suggest that establishing legal frameworks that support enforcement and assign prevention and cleanup responsibilities would, in turn, support improved health of both Mexico's waterways and coastal areas. Although specific data for the volume of plastics that flow into Mexico's waterways are incomplete, there is no question that Mexico faces the same waste management challenge as every other coastal nation. Further, as with other nations, the governance structures for managing solid waste are not necessarily well designed to meet the challenge.

Solid waste management in the Republic of Mexico is structured as a system that provides federal, state, and municipal levels of waste management. Each one of these jurisdictions is responsible for its own regulation and management of three different categories of waste (dangerous, special management, and solid waste). While the separation of responsibility is intended to be clear on paper, the realities of waste management have exposed some legal gaps that have adversely affected Mexico's waterways. Overlapping jurisdiction has fragmented and hampered enforcement, highlighting the need for an integrated federal policy that clearly defines how responsibility is to be shared among jurisdictions and lays out a clearer path to achieve good waste management.

In addition to the variability in the regulatory framework, the variability in financial and management capacity of the different agencies at the three levels of government complicates management because it creates jurisdictional conflicts that can countermand the allocation of responsibility among them. It has become clear that the current system is not the best legal framework to address the complex problem of managing plastic waste in aquatic environments, especially when it comes to watersheds where in-water pollution inevitably crosses jurisdictional boundaries.

In part one of this chapter, the challenges of plastics in the environment are explained, the current legal system in Mexico is described, and some of the harmful effects that the jurisdictional distribution generates are discussed. Part one also explores how the current system creates gray areas of responsibility for the entities responsible for regulation and, from an economic standpoint, the technical and financial limitations that municipalities face in addressing this problem. The difference in economic growth between the northern and southern states has generated a gap in the capacity to collect and treat solid waste and to enforce environmental regulations at municipal and state levels. Even where there is the capacity, there are few incentives to aggressively address solid waste management problems and insufficient incentives for community and private sector participation in preventing waste from escaping into the environment.

There are three ways to dispose of plastics after their end of life. The first is recycling, which accounts for about 9% of all plastic made to date [1]. The recycling rate has fallen since the Chinese stopped accepting imports of recycling in January 2018 [5]. The second is incineration, which may or may not be used for energy, and accounts for 12% of all plastics made to date [1]. The third is confinement in landfills. Recyclability of plastics is, for many polymers, not feasible and is more theoretical than realistic. In many cases, the technology to recycle certain waste

plastics is simply not available or is cost-prohibitive. Likewise, many complex polymers and combined polymers cannot be recycled. Barriers to prevention (better waste management), barriers to recycling, and barriers to enforcement need to be addressed at every level.

Thus, part two focuses on how federal policy could better address how plastic is made, how to improve the safety of plastics, and how plastics can generate economic value. If plastic's ability to generate economic value was addressed in policy, it would incentivize for post-consumer plastics to be recycled in ways that displace primary production, rather than delaying final disposal. Such a policy would establish a hierarchy of plastics, meaning prioritizing those with uses that are a benefit to society and moving toward an end to single-use plastics that have no clear benefits. It would prohibit the manufacturing of toxic plastics and support more dispersed technological capacity.

2 Part One: Plastic Waste in Mexico: The Problem and Current Legislative Frameworks

2.1 Plastic Waste in Aquatic Environments

Durability, flexibility, and adaptability: the very qualities that make plastic so useful are those that have created a serious challenge to global environmental health. Plastic fragments into ever-smaller pieces over time, rather than decomposing as does paper or wood. The sheer volume and effect of plastic waste in aquatic environments is the subject of a rapidly expanding body of global research. The effects of plastic waste are better understood in marine than freshwater environments [6]. Plastic debris found in waterways ranges from macroplastics (e.g., tires, furniture, fishing gear, bottles, bags, or car parts) to microplastics (e.g., microbeads and fragments from macroplastics <5 mm).

Microplastics are of particular concern because they not only provide a surface for the accumulation of waterborne contaminants such as heavy metals but are also consumed by aquatic animals and found in drinking water all over the world [6]. Thus, the nature and sources of microplastics in waterways must be understood in order to establish the legal framework for addressing plastic pollution in waterways.

Researchers generally classify microplastics (particles smaller than 5 mm) in five general categories: foam (e.g., polystyrene), microfibers (e.g., from textiles, fishing gear, and cigarette filters), spheres (e.g., microbeads from cosmetics and pre-production pellets known as nurdles), fragments from larger debris, and films (e.g., breakdowns from plastic bags and wraps). Rubber and synthetic tires are also a source of microplastics. In a 2019 study, Sutton et al. [7] report that particles from vehicle tires make up almost half of the microplastics in San Francisco Bay.

Standardization of definitions, quantification methods, and research of the effects of aquatic plastic pollution on human and environmental health is slowly evolving and remains necessary to inform plastic policy. Defining the constituent polymers of individual plastic applications is also important to legal frameworks. For example, some polymers are individually recyclable but not recyclable when combined or adhered to one another for specific applications. Other polymers are not safe for use in consumer applications (i.e., cannot be used for food packaging) but are part of the waste stream and thus may wind up in waterways, break down, and become part of the food chain or contaminate drinking water [8]. Other polymers were combined with heavy metals such as cadmium or lead to achieve certain colors until the early 1990s [9] and thus represent an additional hazard as they break down in aquatic environments. The complexity of the vast array of polymers in use makes designing good regulatory governance challenging. At the same time, prioritizing human and environmental health within those legal structures will support the phasing out of the least desirable, most dangerous polymers and plastics.

2.2 Overview of Relevant Mexican Legal Structures to Address Plastic in Waterways

It has been widely confirmed that a direct link between an increase in economic development and waste exists. Mexico has not been an exception. Based on governmental information [10], urban solid waste increased by 25% to an estimated 41 million tons per year from 2003 to 2011. Part of that growth was fueled by an ever-growing per capita consumption of bottled water. Mexico has long been among the top consumers of bottled water in the world [11].

Production of urban waste is asymmetric within the country. The northern part of the country and Mexico City contribute to approximately 79% of all urban waste, with production in Mexico City of about 1.8 kilograms per person per day [12]. Fortunately, those high waste-producing states are the ones with the stronger collection services in their municipalities. Nonetheless, there is minimal legal structure in place to address increasing waste streams and the compounding problem of plastic waste remains, especially in waterways.

Until 2016, Mexico had 31 states and 1 federal district, Mexico City, which is now the 32nd state. Each state is formed of municipalities. There are about 2,457 of them throughout Mexico, while Mexico City is divided into 16 administrative divisions. The Federal Congress (Congress) can legislate to establish the concurrent authority of federal, state, and municipal governments which regulate, within their jurisdiction, the:

- Protection of the environment
- Preservation and restoration of the ecological balance
- Environmental damage, repair, and compensation

Federal statutes stemming from the Constitution provide the framework and basis for the national environmental regulatory scheme. International instruments such as international treaties or trade agreements are also a source of environmental law. Their influence has shaped the environmental regime and provided instruments to enforce environmental legislation.

2.2.1 Constitution

The 4th Article of the Mexican Constitution declares that all persons have the right to a healthy environment for his or her development and well-being [13]. The federal government is required to defend this right, and responsibility falls on those who cause any environmental damage or deterioration. Furthermore, paragraph 4 of Article 27 [13] stipulates that all waterways and water bodies are the property of the Nation; thus the executive branch is the entity in charge of regulating them. In this sense, from the interpretation of the two constitutional articles cited, the executive federal branch is the sole entity in charge of environmental preservation of all waterways and water bodies, thus in preventing or remediating harm.

2.2.2 International Conventions or Treaties

Mexico is party to the following conventions with regard to ocean pollution:

1. Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter 1972 [14]
2. International Convention for the Prevention of Pollution from Ships [15]

In both conventions, plastic litter and therefore pollution are subject to prevention. Nonetheless, it is clear that these conventions were not intended to address land-based plastic litter that ends up in the ocean, which is estimated to be roughly 80–90% of plastics in the ocean [16, 17]. In addition, the London Convention specifically exempts pollution emitted by energy or vessel operations at sea, which limits the London Convention's jurisdiction over ocean plastics that derive from those activities [14].

Mexico is also party to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, which is generally considered to be the most comprehensive international agreement on hazardous and other wastes. In May 2019 approximately 180 governments ratified an amendment to the Convention to "include plastic waste in a legally binding framework which will make global trade in plastic waste more transparent and better regulated" [18].

Mexico has also committed to meeting the United Nations Sustainable Development Goals (SDGs) [19]. SDG 14 calls for countries to "conserve and sustainably use the oceans, seas, and marine resources for sustainable development." SDG 14.1 sets a target of preventing and significantly reducing "marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient

pollution" [20]. In addition, SDG 6 focuses on access to and good management of clean water for human communities and natural habitats. SDG 6.3 sets the goal of improving water quality by "reducing pollution, eliminating dumping, and minimizing release of hazardous chemicals and materials" with those improvements to have achieved significant improvement by 2030 [21]. Finally, SDG 12 commits countries to pursuing sustainable consumption and production patterns [22].

2.2.3 Federal Legislation

1. General Law for the Prevention and Integrated Management of Waste (General Law)

On October 8, 2004, the federal law to promote prevention of waste and integrated waste management was enacted. It established the classifications for dangerous residues, special management of solid waste, and defined specific management strategies according to international standards [23]. Furthermore, the 25th Article provides the concept of a national program for the prevention and integrated management of waste, which has to be based on reducing, reusing, and recycling. The concept of shared and differentiated responsibility among the different sectors of society was introduced, just as it was at the three governmental levels.

A 2014 amendment to subpart III of Article 28 established the sectors that were obliged to be defined and required implementation of a management plan. These are big generators, producers, importers, exporters, and distributors of products that become solid waste at their final stage. This includes plastic wraps, expanded polystyrene, as well as importers and distributors of used tires, subject again to the principles of valorization and shared responsibility [24].

The concept of industry responsibility is embedded in the last paragraph of Article 100, which expressly mandates that manufacturers, importers, distributors, and generators are obliged to take care of the administration and recollection of used tires [25]. Such a specific defined obligation does not yet exist for the plastic sector.

However, the 2014 amendments establishing mandatory management programs for certain plastics have improved the management of these plastics. The improvement has been more noticeable in how plastic waste is confined and disposed of post-use, rather than improved recycling rates or changing the chemistry of polymers.

2. The National Water Law

The National Water Law of 1992 (revised in 2004) is the main law governing water resources management, affirming the federal responsibility through the National Water Commission, CONAGUA (CNA). The law also provides that whoever pollutes must pay for the remediation of the waterways (Article 14 Bis 5, subsection XVII).

Furthermore, Article 86 Bis 2 defines what may not be thrown away or deposited in water bodies. Not all the water in the country is under federal jurisdiction. "Discharge water bodies" and federal zones are described in paragraph 5 of Article

27 of the Constitution [13]. Generally, all trash and any residues from its dissolution that contaminate the bodies of water are prohibited.

3. The Law [limiting] Dumping in Mexican Marine Areas (*Ley de Vertimientos en las Zonas Marinas Mexicanas*) (LVZMM)

The law requires permits for any dumping into marine waters and includes processes for permitting of activities that result in waste such as drilling. Mexican's civil law system prohibits those activities that are not specifically allowed. Thus, any dumping without a specific permit will be considered an illegal action under this law [26].

4. The Federal Oceans Law (Ley Federal del Mar)

The law was established in the wake of the entry into force of the United Nations Convention on the Law of the Sea in 1974. The law does not mention the topic of plastics or marine debris, but it does establish that Mexican ocean waters are federal and managed under sovereign authority, including the 200-mile exclusive economic zone (EEZ) [27].

2.2.4 Relevant Federal Regulatory Authorities in Mexico

1. The Secretariat of the Environment and Natural Resources (SEMARNAT) is the main federal agency in charge of enacting and enforcing environmental regulation.
2. The Office of the Federal Prosecutor for Environmental Protection or PROFEPA is the enforcement arm of SEMARNAT.
3. The National Water Commission (*Comisión Nacional del Agua)* has oversight of water resources, in coordination with the Mexican Institute of Water Technology (*Instituto Mexicano de Tecnología del Agua*).

Water legislation is subject to overview and implementation by the federal government. The national waters law establishes that the federal government as the competent authority may delegate to individual ministries within the federal government. Therefore, any federal ministry might be given an area of coordination or responsibility if necessary [28].

2.2.5 Mexican Official Norms (NOMs) and Voluntary Guidelines (NMX) Regarding Plastics

NOMs are technical standards issued by the relevant authorities to implement legislative directives. NOMs establish binding specific standards for products, processes, facilities, systems, activities, services, or methods of production. NOMs establish the allowable pollutant limits for contaminants in air, water, and soil. In addition, NOMs specify what qualifies as hazardous waste or hazardous substances.

NOMs may also list specific entities or types of entities that must comply with the standards. NMX rules are those that are intended to serve as guidelines, and compliance is generally voluntary rather than mandatory [29].

1. NOM-161-SEMARNAT-2011 defines the criteria for waste materials that require a management plan, as well as a list of materials themselves. As provided in the General Law in the annex of this Official Norm, it establishes the responsibilities of big generators of plastic waste. These are defined as those that generate more than 10 tons of specific plastics per year in the following economic sectors:

   (a) Health (plastic in general)
   (b) Agriculture, specifically agroplastics (those used for crop covers and weed control)
   (c) Transportation, including maritime, aerial, and ground shipping
   (d) Retail (e.g., department stores, shopping centers, and public markets), specifically polyethylene terephthalate (PET), polystyrene (PS), and polythene (PE) bags
   (e) Retail and wholesale regarding PET, PS, and PE film
   (f) Any other activity that generates more than 10 tons a year of plastic waste, including public advertisements and political campaigns regarding low-density and high-density polyethylene, polyvinyl chloride (PVC), polypropylene (PP), PS, and polycarbonate (PC)

This NOM defines a clear approach to the shared responsibility principle (from a federal perspective) as it is intended that each named industry must share the responsibility for the waste of the products they use or generate. In section 9, it is provided that each participant in the management plan, in order to be authorized by the ministry of environment (SEMARNAT), has to include the shared responsibility principle of all the entities involved in the value chain. It is the first time this concept was published in a federal mandatory rule.

2. NMX-e-232 Plastic Identification Symbols

The voluntary guideline establishes and describes the identification symbols that all plastic products need to have regarding the type of materials used in their production, in order to facilitate the selection, gathering, collection, recycling, or reuse.

3. NMX-e-233 Recycling Terminology

Uniform standards are essential to manage all plastic. The voluntary regulation provides standardization of the terms used in the plastics recycling process, in order to avoid the use of more than one term or meaning and thus to ensure that polymer identification is consistent and permitting is product specific.

4. NMX-e-260 Bioplastics Terminology

This voluntary regulation standardizes the terms related to bioplastic materials in order to avoid more than one meaning for individual terms. The result is a standardized framework for assessment.

5. NMX-e-267 Methods of Testing of Bio-Based Plastics

The voluntary regulation establishes two testing methods to determine the bio-based content in resins and plastic products that are manufactured, commercialized, and distributed within the Mexican territory to further determine whether a given product may be incinerated and how much CO_2 it will emit when burned. This regulation is intended to bring Mexico's incineration standards into compliance with the rest of the world, via following the International Organization for Standardization (ISO) standards for carbon content (and thus emissions) when incinerating waste.

- ISO 16620-1:2015 Plastics-*Biobased Content-Part 1: General principles*. Primera Edición 2015-04.
- ISO 16620-2:2015 *Plastics-Biobased Content-Part 2: Determination of biobased carbon content*. Primera Edición 2015-04.
- ISO 16620-3: 2015 *Plastics-Biobased Content-Part 3: Determination of biobased synthetic polymer content*. Primera Edición 2015-04.

Plastics-Biobased Content-Part 3: Determination of biobased synthetic polymer content:

- ASTM D6866-12 *Standard Test Methods for Determining the Biobased Content of Natural Range Materials Using Radiocarbon and Isotope Ratio Mass Spectrometry Analysis,* PA, 2012.
- EN 16640 *Biobased Products-Determination of the biobased carbon content of products using the radiocarbon method*
- EN 16785 *Biobased Products-Determination of the biobased content using radiocarbon analysis and elemental analysis. (More biobased content standards are in being developed.)*

ISO works with standards institutes from over 150 countries to develop technology and product standards to enable global exchange of products [30].

2.2.6 State Legislation Governing Plastics

On April 22, 2003, the first Mexican law that regulated single-use plastics was enacted in Mexico City, which was then still a federal district. In Article 26 Bis, all plastic bags that would be distributed as a result of a commercial operation had to comply with the criteria provided in Article 6 subpart XI regarding the reuse and recycling of plastics.

In addition to the regulation noted above, the city government signed a collaboration agreement with the owners of restaurants and bars in 2018 to reduce the use of straws. Under the revised Mexico City regulations, commercial use of plastic bags

will be banned after 2020. After 2021, commercial sale and use of single-use plastics will be banned. This includes cutlery, balloons, cup lids, straws, and products containing microplastics (Tables 1 and 2).

The patchwork of regulation presents its own problems for both compliance and enforcement. In addition, the legal definitions of plastic products are inconsistent, vague, and often unscientific. It is possible that this vagueness derives from the plastic industry's opposition or the legislative process that incorporates multiple different perspectives, approaches, and interests. In any case, as governments around the world seek to draft legal frameworks to address the ubiquity of plastic waste and prevent additional waste, it is clear that good legal definitions are absolutely critical to enforcement. Without them, there are too many ways to evade polluter responsibility.

Finally, an entity that is subject to management programs established in the federal residues law deserves a special mention. It was created as an alternative to the inherent weakness of municipalities. Municipalities are under considerable financial and political restraints. This is due to the fact that Mexican mayors are in office for one 3-year term, which presents a challenge for any long-term planning including the management that urban solid waste requires. Thus, federal authorities have sought to balance this limitation with alternative entities.

In 2002, the industry succumbed to government pressure to establish the Ecology and Corporate Commitment (ECOCE), which was intended to generate a regular flow of plastic that recyclers could depend on. It was hoped that ECOCE would both provide economic opportunities and a reduction in plastic bottles as waste that eventually found their way to waterways. By 2012, recapture of PET bottles had more than tripled to 35% – in part due to external investment in Mexico's capacity to recycle with a new plant capable of producing new PET bottles from recycled materials [51]. Accepting external investment helped with enforcement of multiple aspects of the operations, including a ban on child labor, safe conditions for workers, and better sanitary conditions for the waste pickers. Providing an additional incentive for government investment was Coca-Cola's announcement of a commitment to ensure that its packaging would achieve at least a 25% minimum recycled content goal.

In 2018, the federal government announced "the Mexican model for the formation of operator agencies for the integral management of urban solid waste as a planning tool for municipalities interested in this operation model, which ensures a comprehensive technical and economically viable management [32]." The goal is to establish a group of specialists from the government, academy, and society that will try to solve the solid waste challenge from a regional perspective. The idea behind the creation of these operating entities for the integrated management of urban solid waste has its origins in a similar entity that was created many years ago to solve the challenge that represents the management of freshwater sources, based on the same technical approach.

Solid waste management may be one of the most visible roles of government; and in Mexico, much of the disposal is undertaken by private companies. Thus, how it is regulated and how contracts are assigned can be politically charged. The idea behind a multi-sectoral committee is to separate responsibility for the planning and

Table 1 State Laws

	State	Regulation	Sanctions
1.	Baja California	Environmental Protection Law of the State of Baja California (Arts. 141 and 187) amendments passed in 2007, 2009, and 2016. Ban on plastic bags [31]	200–20,000 UMAs (16,898–1,689,800 pesos)
2.	Baja California Sur	Environmental Protection Law for the State of Baja California Sur, which establishes the elimination of the use of plastic bags and expanded polystyrene containers, as well as plastic straws in establishments of the entity [32]	No sanctions
3.	Campeche	Amendments in review, not approved yet	
4.	Chiapas	Environmental Law for the State of Chiapas states the elimination of the sale and use of plastic bags and expanded polystyrene (unicel) containers for single use, for the purpose of wrapping, transportation, cargo, or transfer of food and beverages, products, and merchandise in supermarkets, self-service stores, department stores, pharmacies, convenience stores, markets, restaurants, and establishments where food and beverages are sold; as well as the delivery and use of single-use polymer-based plastic straws, for food use in bars, restaurants, and the like, and other products derived from plastic for disposable food, entertainment, hygiene, and personal-use utensils. First use, such as plates, spoons, forks, swabs for cotton swabs, glasses, trays, balloons, sticks for balloons, and other policies that promote the final replacement of these, for products made with materials that facilitate their reuse or recycling and that are of rapid biodegradation or compostable products (Arts. 1, subsection XVII, 238 Ter) [33]	No sanctions
5.	Chihuahua	Law for the Prevention and Integral Management of Waste of the State of Chihuahua (Arts. 21 and 74). Ban on plastic bags, packaging materials cannot be made out of plastic, and prohibits use of straws in restaurants [34]	20–50,000 UMAs (1,689.8–4,224,500 pesos)
6.	Coahuila	Law of Ecological Balance and Environmental Protection of the State of Coahuila de Zaragoza (Arts. 104 Bis, 150 Bis, 156 Bis, and 182 Bis). Prohibits the ability to give away or use of disposable plastic bags for hauling, loading, wrapping, or packing products, whether for free or for sale, to give straws, and use of foam (unicel) [35]	20–50,000 UMAs (1,689.8–4,224,500 pesos)

7.	Durango	Sustainable Environmental Management Law for the State of Durango (Arts. 5th, fractions XXXIX, XL, XLI, and 134) Reduction of plastic bags and straws [36]	20–20,000 UMAs (1,689.8–1,689800 pesos)
8.	Guerrero	Law for the Use and Integral Management of Waste from the State of Guerrero (Art. 49 Bis), which prohibits commercial establishments from using plastic bags and delivering to the consumer expanded polystyrene containers, straw, spoons, and glasses [37]	No sanctions
9.	Jalisco	State Law of Ecological Balance and Environmental Protection, prohibits all use of plastic bags in commerce, giving out straws, and foam. May allow recyclable materials in 2020 [38] (Arts. 6th, 7th, 8th, and 148)	20–20,000 UMAs (1,689.8–1,689800 pesos)
10.	Mexico City	Solid Waste Law for Mexico City (Federal District) Prohibits the marketing, distribution, and delivery of plastic bags to the consumer at points of sale of goods or products, except if they are compostable. The marketing, distribution, and delivery of forks, knives, spoons, mixing sticks, plates, straws, cotton swabs, balloons and sticks for balloons, glasses and their lids, trays for transporting food, and tampon applicators are made entirely or partially of plastics, designed for disposal after a single use, except those that are compostable. Marketing, distribution, and delivery of straws for medical assistance are excluded. The commercialization, distribution, and delivery of products containing intentionally added microplastics. The marketing, distribution, and delivery of single-use coffee capsules made of low plastic materials; exploitation potential [39]	
11.	Morelos	State with intention to legislate	
12.	Nayarit	State Law on Ecological Equilibrium and Protection of the Environment (Art. 2, subsection IX). Actions aimed at the prohibition and elimination of the use of bags, straws, plastic containers, unicel, or those made with materials toxic or environmentally harmful premiums for wrapping purposes, transportation, loading, or transport of food and beverages [40]	

(continued)

Table 1 (continued)

	State	Regulation	Sanctions
13.	Nuevo León	Environmental Law of the State of Nuevo León (Arts. 168 Bis and 232). Amendment of Chapter IV of Title IV, and by adding Articles 168 Bis and 168 Bis I, of the Environmental Law of the State of Nuevo León. It was presented by Deputy Felipe Hernández, from January 25, 2020, in which the sale, gift, and use of polyethylene, polypropylene, and plastic polymer straws is prohibited [41]	20–30,000 UMAs (1,689.8–2,534,700 pesos)
14.	Oaxaca	Law for the Prevention and Integral Management of Solid Waste (Arts. 16 and 99). Prohibit merchants from providing plastic bags, unless they are biodegradable, and the use of unicel in commercial premises	No sanctions
15.	Puebla	Law for the Prevention and Integral Management of Urban Solid Waste and Special Management for the State of Puebla. Prohibits the delivery of plastic bags and straws in business [42]	
16.	San Luis Potosí	Environmental Law of the State of San Luis Potosí (Arts. 104, fraction V, subsection C, 107 and 159) [43]	50–60,000 UMAs (4,224.5–5,069,400 pesos)
17.	Sonora	Law of Ecological Balance and Environmental Protection of Sonora (Arts. 136, fractions X and XI, 143 Bis, and 196) Reform of the law to prohibit the distribution and use of plastic bags by any type of establishment [44]	The penalties that would be given for breaking the rule would range from 50 to 100 UMA daily, meaning every day that the establishment is not in compliance with the law, they are penalized
18.	Tabasco	Environmental Protection Law and the Law for the Prevention and Integral Management of Waste, both of the State of Tabasco, to prohibit the use of straws, plastic bags, and unicel [45]	

19.	Tamaulipas	Code for Sustainable Development of the State of Tamaulipas (Arts. 36, numeral 6th, 7th, and 299) The state and the municipalities, within the scope of their respective competences, will promote the research, development, and application of technologies, equipment, processes, and systems that allow to prevent, control, and reduce pollution in the production, use, and disposal of plastic bags, in order to contribute to the negative impact on the environment in its life cycle, as well as to the reduction in the source, separation, reuse, and where appropriate, the recycling thereof [46]	100–500 UMAs (8,449–42,245 pesos)
20.	Tlaxcala	Law of Ecology and Environmental Protection of the entity stipulated an equivalent fine on average of 422.45 pesos to 8449 pesos. Approved by Congress on March 12, 2019, and then rejected by the executive branch in June 2019	
21.	Veracruz	Law on Prevention and Management of Urban Solid Waste and Special Management for the State of Veracruz (Arts. 1o., subsection XIII and XIV, 23 Ter and 79). Reduce the use of straws and plastics in state territory 21 with the aim of curbing environmental damage to bodies of water and marine fauna [47]	1,000–80,000 UMAs (84,490–6,759,200 pesos)
22.	Yucatán	Executive branch sent to Congress for review the Law for the Integral Management of Waste, which contemplates the decrease and gradual elimination of the use of plastic bags and straws, on January 15, 2019	

The Unit of Measurement and Update (UMA) is the economic reference in pesos to determine the amount of payment of the obligations and assumptions provided in federal laws, of the federal entities, as well as in the legal provisions that emanate from all the previous ones [48]
Modified from Jatziri Pando Medina with information obtained from the United Nations Environment Program for Mexico and other legal sources [49]

Table 2 Municipal regulations [50]

	Municipalities
Proposal to legislate	Campeche, Campeche, Colotepec and Pochutla, State of Oaxaca and Cuernavaca
Reduction to use plastic bags	Ciudad Victoria, Pabellón de Arteaga, Querétaro
Reduction to use plastic bags and give out straws	Ciudad de México, Monterrey
Ban of plastic bags	Saltillo, Tijuana, Playas de Rosarito
Ban on plastic bags, straws and foam	Huatulco, San Agustín de las Juntas, Oaxaca de Juárez, Tlalnepantla, and Toluca
Ban on plastic bags, straws, cutlery and foam	Cancún, Ensenada, Islas Holbox, Metepec, Pátzcuaro, Santa Catarina Lachatao, Santo Tomás Jalieza, San Bartolo Coyotepec, State of Oaxaca

Translated from Jatziri Pando Medina with information obtained from the United Nations Environment Program for Mexico and other legal sources [50]

implementation of waste management solutions from mayors and other entities, who are less likely to insist on long-term solutions because their own terms are so short. The multi-sectoral entity is conceived as a legal and financial structure independent from the government.

The multi-sectoral committee draws on the public and private sector as well as social organizations, for the sole purpose of approaching the regional problems from an environmental, social, financial, and technical perspective based on the circular economy paradigm. When first announced, the federal administration saw this initiative as a critical step toward its goal of transitioning to a zero-waste economy, based on the 2030 Agenda, a goal shared by the new administration's environmental authority.

Likewise, Mexico's Congress has recognized the need to create a national framework for plastic manufacturing, use, and disposal that creates a common national system for addressing this problem. Several measures to amend the national law have been introduced and are to be considered before the end of 2020. Also included in these proposals is an extended liability regime that is intended to improve labeling, recovery, and separation, and in turn, better recycling. It is expected that if this reform takes place, both production and consumption will be addressed formally to further circular economy goals.

2.3 Conclusions About Mexico's Legal Framework

Mexico's waterways are protected in the Constitution and by law [13]. Plastic waste in those waterways is a harmful contaminant, and thus legal frameworks must emphasize the responsibilities of producers and the prevention of plastic waste in the environment.

To date, legal efforts have focused on identifying bigger producers and mandating their responsibilities, as well as congruence with the overarching goal of advancing international legal instruments to address plastic pollution globally.

Mexico's efforts to legislate improved management of plastic waste have resulted in better attention to what happens to plastic waste. With the cooperation of entities that produce more than 10 tons of plastic waste per year, more post-use plastic is properly disposed of and contained. At the same time, the jurisdictional differentiation has not been fully resolved. All the waterways may be nominally identified as federal resources, but the waters flow through states and municipalities – many of which lack sufficient collection, waste management, and enforcement infrastructure.

It is hoped that the establishment of the multi-sectoral committee as described above will improve collection and disposal at every level. Likewise, the capacity and willingness to recycle simple plastics such as PET bottles need to be further incentivized in the legal structure, as global prices for virgin materials (especially in the United States) have dropped due to higher production capacity [52]. When the recycled material is less expensive than virgin polymer, either because of availability or taxation, more PET bottles are recycled instead of dropped into waterways [53]. Incentives for the enforcement of labor and sanitary conditions for workers need to be incorporated into the legislative framework.

It still remains for a federal legislative framework to directly reduce long-term production of plastic waste; it needs to identify which plastics are the most value added to society and which present more cost than good to society. Public pressure has generated one aspect of a plastic hierarchy in that the public has been willing to accept legislated bans on bags and straws in some of the most populous states. Reducing the use of PET bottles may be more of a challenge given public perceptions of public water supply safety. At the same time, mandates on producers to increase recycling rates (and recycled content) might support reduced waste and the prompt identification of environmentally safe, economical substitutes for all single-use plastic containers and packaging.

Such a legislative framework must also incentivize research into solutions, reward innovation and waste reduction, and mandate consideration of the environmental cost of products accounting for where it is sourced (and from what), how it is used, and how it is disposed of. Ideally the proposed national legislation adequately considers both immediate solutions (a consistent national law governing single-use plastics) and the more critical issue of integrating extended producer responsibility.

Mexico's vital water resources are protected as a constitutional right of all people of Mexico. Well-drafted federal legislation to manage plastic production and waste with the appropriate local and state incentives can help reduce the threat to healthy aquatic environments that is posed by plastic waste. It can reduce jurisdictional overlap and increase jurisdictional cooperation. It can help Mexico to achieve its national and international sustainability goals.

3 Part Two: Framing Future Legal Structures for Plastics in Mexico

3.1 Introduction

In designing a framework for a national legislative approach to address plastic pollution in the waterways of Mexico, the following question must be answered: How can plastic pollution best be addressed in such a way as to reconcile legal differences among states, clarify jurisdictional responsibilities, and prevent future harm to the environment and public health in Mexico?

Such a framework incorporates a hierarchy of plastics, identifying those that are beneficial to a healthy society and those that are negative. In turn, the hierarchy suggests which plastics should and should not be in the stream of commerce. From there, the framework focuses on ensuring sufficient consistency in which polymers are used for the chosen plastics. Consistency enhances the value of the residuals to ensure they will be recycled.

Designers of the hierarchy must ensure that it considers existing technology; how plastic is made, used, and disposed of; and how the producers and users of plastic can be incentivized to cooperate in the development and implementation of good legislative solutions. Any legislative solutions must also include mechanical approaches to preventing plastic waste from accumulating in waterways and address obstacles to better disposal practices.

Even as the framework is being developed, governments and consumers must also maintain the pressure on the private sector to contribute to solutions. Those solutions cannot be limited to simplistic strategies for managing what is already on the shelf and in the waste stream but incorporate the principles of safety for humans, safety for the environment, and recyclability. To propose and enact improvements in plastic production, use, disposal, and recycling establish the foundation for a more sustainable society.

3.2 When Plastic Is Not Pollution

Plastic use in today's society is unavoidable. Petrochemicals are used in everything from plastic straws to packaging to medical equipment, clothing, and tires. The polymers seem endlessly adaptable – from keeping tea bags intact to the thermoplastic foams that make wind turbine blades more durable [52]. It is not hard to understand why society has invented, produced, and embraced plastics. They are durable, adaptable, and useful, even if they pose a management challenge at the end of their useful life. It is about cost, convenience, light weighting, public safety, and moldable design utility. Plastic applications are being used to address environmental challenges as well.

For example, plastics are being used to reduce the carbon footprint of some sectors, reducing energy use and increasing efficiency. High-performance plastics are already used to make components of airplanes, cars, buses, and trucks, which lower their weight, fuel consumption, and lifetime emissions [52]. Plastic content can be increased to continue to reduce carbon emissions from our most fossil fuel-dependent sector: transportation [54]. Likewise, composites used to increase efficiency or improve durability in renewable energy systems are part of the solution to moving away from burning fossil fuels for electricity and heat, which is the source of 25% of global greenhouse gas emissions [54].

Society cannot condemn all single-use plastics. Governments should prioritize the applications (or products) by how they are beneficial to a healthy society. For example, the relatively small percentage of plastics produced for the medical and dental industries – from hypodermics to prosthetics, from catheters to equipment housings – have helped to reduce infections, limit disease transfer, and improve patient health [55]. While there are ways to reduce the use of single-use plastics in hospitals and other medical settings, it is not possible to achieve comparable hygiene or utility in all areas of health care without plastic.

Likewise, bottled water has also improved community health in many ways, even though it represents a significant cost to consumers. Mexico has the highest per capita consumption of bottled water in the world [11]. This is in part because the capacity of the country's public water systems has not kept up with population growth and in part because of community skepticism about the safety of tap water [11]. The use of purified bottled water has reduced certain diseases such as cholera [11]. Yet, improving water treatment and access to clean drinking water via public systems would avoid leaching of chemicals into the water from the standard 20-L plastic household containers and also address the disposal problem for bottles and other containers that present their own threats to communities and environmental health [56].

Single-use plastics can reduce waste overall – as long as there is an appropriate end of use option for such plastics, they can also be considered beneficial. For example, safe and recyclable polymers for packaging food can help reduce food wastage, which has its own carbon footprint [57]. The value added by single-use plastics must also be weighed against the cost.

Society needs to recognize that extracting fossil fuels to produce single-use plastics for packaging, fast food meals, and other uses causes significantly more harm than good. To help change this mindset, alternatives to single-use plastics should be incentivized. In order to avoid plastic pollution, policymakers need to identify and incentivize the use of recyclable polymers that are safe for communities, the environment, overall human health, as well as being attractive to recyclers and investors. Eliminating plastic pollution depends on multiple strategies, among others, good legal frameworks, and the will to enforce the law in the interest of public welfare.

3.3 Plastic Is Pollution

The definition of pollution is the introduction of harmful substances into the environment. Thus, by definition plastic that enters the environment is a form of pollution. The recognition that "plastic is pollution" is global, due in part to a series of well-publicized discoveries of the breadth and depth of its presence in our global ocean. More than 80% of marine litter is composed of plastics [58].

Plastic, once in the ocean, can be deadly to ocean life [59, 60]. Lost fishing nets, traps, and other gear continue to kill animals for years. When animals become entangled in lost gear or other plastic debris, they can suffocate. Accidental consumption of plastics while feeding fills stomachs and other body cavities that displace real food and causes starvation in sea birds and other animals. Plastic carries toxins, bacteria, and viruses, which can kill marine animals. In addition, plastic transports marine life from one environment to another, thus contributing to the displacement of native species by alien and invasive species, with the accompanying socioeconomic costs [59].

Plastic pollution adversely affects coastal activities that support Mexico's economy. Dirty beaches are less attractive to tourists and other recreation-seekers [61, 62]. Lost fishing gear and other large debris tangle propellers and harm productive habitats such as coral reefs [59]. Floating plastic can prevent light from reaching the riverbed or seafloor and thus adversely affect aquatic life. If the plastic sinks, it can interfere with plant growth and the benthic community. Moreover, as microplastics are increasingly discovered in seafood, public trust in its consumption is diminished [59].

Removing all plastics, especially microplastics, from waterways remains an unsolved challenge. Preventing future pollution offers more opportunities for success.

3.4 Country-Level Legislative Actions

As the UN Environment Program notes, 50 years of exponential growth in plastic production has created centuries of durable, persistent pollution [63]. About half of all plastics produced globally in any given year is used for single-use containers and packaging, a category that includes bags and wraps, polyethylene terephthalate (PET) bottles and jars, high-density polyethylene (HDPE) natural bottles, and other packaging and containers [59]. Thus, it makes sense that it is these single-use, low-value applications that have drawn the most legislative attention to date.

National and regional governments are moving to limit or eliminate certain plastics that are unnecessary or easily replaced [63]. For example, in 2019, the European Parliament approved limitations on single-use plastics beginning in 2021 [64]. In passing such measures, the European Union joined more than 30 nations who had already done so – many of them in sub-Saharan Africa. The majority of

national laws targeted plastic bag use in commercial settings (e.g., stores issuing them as carriers rather than manufacturers' packaging). Nations across the globe have taken such action, for example: Antigua and Barbuda (2016), Bangladesh (2002), Cameroon (2014), Colombia (2017), Samoa (2018), Senegal (2015), Rwanda (2008), South Korea (2019), and Tunisia (2017) [65] (Table 3).

Public awareness campaigns and boycotts have generated sufficient consumer-driven pressure to enact legislation banning certain single-use products and microplastics such as microbeads. Public engagement is one strategy for reducing plastic pollution. Likewise, campaigns to pick up and capture plastic waste on land and in waterways before it reaches the ocean play a role in preventing plastics from polluting the ocean. These campaigns have the added social and economic benefit of improving the visual appeal of riparian and coastal areas [61]. However, such activities can only go so far in addressing the problem of plastic waste from all uses over the long term. The long-term solution lies in limiting even the potential harm from plastic creation, application, use, and disposal.

The fossil fuels that underpin plastic production are inherently polluting as is the process of extracting them. Petrochemical plants are known emitters of community-based air and water pollutants. The toxicity of mixing two or more theoretically food-safe polymers is suspected but not fully understood. Waste plastic in the environment is known to harm the environment in multiple ways. Any remedy needs to prioritize safety and minimize negative effects. Legislation needs to safeguard human health, the terrestrial and aquatic environment, including plants and animals, as well as incentivize maximum recapture and reuse to reduce the demand for virgin product (and the extraction of fossil fuels the extraction necessitates).

3.5 Incentives to Participate in Solutions

It is important to consider the challenges in designing incentives for the private sector to fully participate in solving the plastic pollution problem. Big consumer brands such as Coca-Cola, Nestle, cigarette companies, and others are vulnerable because their products consistently show up on beaches and along waterways during cleanup events that include formal data collection [67]. While all sectors are feeling pressure to reduce plastic waste in the environment, not every sector is equally visible to the public.

The demand for plastics presents a significant obstacle to addressing the root causes of plastic pollution in waterways and the ocean. Based on recent investments, the petrochemical and plastics industry projects exponential growth over the next few decades [68]. Since 2010, $200 billion has been invested in the capacity to produce petrochemicals in the United States alone [69]. Global investment in production capacity is following a similar pattern [52, 70]. This kind of investment implies that plastic producers are confident that demand will continue to grow for their products despite the growing number of countries that are considering or implementing legislation to address single-use plastics. At the same time, producers

Table 3 Types of plastic and their uses [66–70]

Type of plastic	Uses
Bio-based plastics	Made partially or wholly from renewable biological resources such as sugar cane (ethylene) or starches (polylactic acid). Even though not fossil fuel based, they still represent a form of semi-permanent pollution in the environment
Biodegradable plastics	Plastics that can be degraded by microorganisms into water, carbon dioxide (or methane), and biomass under certain defined conditions such as minimum temperature or moisture content (e.g., composting). It can be challenging to meet the defined conditions in uncontrolled outdoor settings or waterways
Engineering plastics	Used to make complicated shapes and/or substitute for wood, metal, and other materials. For example, they are used in the manufacturing of cars or airplanes to make them lighter but still strong
Epoxy resins	This form of plastic can be found in a broad array of applications – from soft drink can linings to protective coatings on garden furniture and wind turbines
Expanded polystyrene (EPS)	Valued for its ability to absorb shock and maintain the temperature of foods, EPS is used for insulation, food storage containers, packaging, and crash helmets
Fluoropolymers	The most well-known representative of fluoropolymers is polytetrafluoroethylene (PTFE), which is considered to be the most slippery material in existence. Among its diverse uses are flame retardants, nonstick cookware coatings, and biomedical applications such as implants
Polyolefins	This family of polyethylene and polypropylene thermoplastics are produced mainly from oil and natural gas and include HDPE (e.g., bottles for food products, detergents, pipes, and housewares), LLDPE (e.g., stretch film and thin-walled containers), LDPE (e.g., cling film and electrical cable coatings), and PP (e.g., carpet fibers, medical packaging, luggage, and food packaging such as yogurt containers)
Polystyrene	Made from the monomer styrene, a liquid petrochemical, it is used to make packaging, household appliances, take-away food containers, construction materials, and many other applications
Polyurethane	It is virtually impossible to avoid polyurethane-containing products because its various types of resilient, flexible, materials are found in everything from building insulation to refrigerators to furniture to footwear to cars, and even as coatings and adhesives
Polyvinyl chloride	One of the first plastics discovered, PVC is also one of the most extensively used. It is derived from salt (57%), oil, or gas (43%). It is the world's third-most widely produced synthetic plastic polymer, after polyethylene and polypropylene. PVC comes in two basic forms: rigid (sometimes abbreviated as RPVC) and flexible
Thermoplastics	These polymers can be melted and recast almost indefinitely and thus are mechanically recyclable. Acrylonitrile butadiene styrene (ABS) is used in sports equipment, to make LEGO blocks, and automobile parts. Other common types of thermoplastics include polypropylene, polyethylene (e.g., shampoo bottles, plastic grocery bags, bullet proof vests), polyvinyl chloride, polystyrene, polyethylene terephthalate, and polycarbonate (e.g., CDs, DVDs, drinking bottles, eyeglass lenses)

are very aware that demand for certain plastics will be greatly reduced following the January 2020 announcement by the Chinese government that plastic bags will be banned in major cities by the end of 2020 and in the rest of the country over the following few years.

Pressure from consumers and governments has appeared to be the reason that more and more companies are committing publicly to reducing the use and increasing the recycling of plastic [52]. The industry-driven, nonprofit Alliance to End Plastic Waste represents one billion dollars of industry commitments as of 2019 [52]. Fortunately, industry remains under pressure to do more, and some of the legislative fixes may provide their own incentives for different actors to participate in solutions (Table 4).

3.6 Design for the Future

Plastic pollution is not just the result of bad consumer behavior, the symptom of a society premised on convenience, or poor municipal solid waste management. It can be argued that plastic pollution is a design problem.

As noted earlier, many polymers and applications were designed to solve individual engineering or chemistry problems. The same multifaceted creative design that went into adapting polymers, films, and foams to thousands of uses can go into their redesign to maximize the recyclability of all necessary plastics. If it cannot be reused, then the product or its components need to be refined until reuse is possible (i.e., make plastic more recyclable). This can include changing formulas and feedstocks, narrowing the number and types of polymers used to only those most easily recycled, identifying alternatives and cleanup options, framing investment needs (such as research, technological capacity, and others), and developing appropriate in-country policy recommendations.

Governments can regulate to reduce the applications that are deemed unnecessary. As they do so, policies regarding necessary plastics need to focus on pre-production, design, and integration of an end-of-life evaluation of each application. Potential recyclability does not mean that recycling is feasible, cost-effective, or within the capacity of every community or every state. New legislative frameworks must also incorporate realistic perspectives about the likely capacity of communities to recycle any given plastic that is in use.

A sustainable future will require rethinking the materials (formulas and feedstocks) used to make products. The rethinking rests on six basic assumptions about plastic in society:

(a) *Food safety* is paramount, and additional independent research is needed to ensure that any potential toxicity from plastics is fully understood.
(b) *Only fully recyclable virgin polymers*, resin, or nurdles should be allowed on the market.
(c) *Responsibility for recovery and reuse* accrues to the manufacturer.

Table 4 Individual interest groups have an incentive to collaborate in rethinking plastic and implementing life cycle policies [55, 71–75]

Interest group	External pressure
The fossil fuel industry, including fracking, is facing:	– Divestiture as shareholders are divesting themselves from fossil fuel companies to reduce their contribution to greenhouse gas emissions – Lawsuits as fossil fuel companies are being sued because their product, when used as directed, causes climate disruption and adversely affects human health – Requirements for "material business risk" disclosure to shareholders by publicly held corporations
Producers of resin, polymers, and nurdles (including such major brands as Dow, DuPont, Monsanto, and ExxonMobil) are facing:	– Outright legislative bans on certain polymers or polymer applications – Legislative incentives to change primary production to make sure it is recyclable and part of the circular economy – Legislative expectation of extended producer responsibility (EPR) for any amount of product (especially nurdles) that escape into the environment – Additional application of EPR to require manufacturers to add all of the environmental costs associated with a product throughout the product life cycle to the market price of that product – Caps on total production volume (stop the production expansion build-out that is enabled by new petrochemical extraction capacity) – Requirements for "material business risk" disclosure to shareholders by publicly held companies – Possible taxes on virgin material to make recycled material more competitive
Engineering of plastic applications, particularly producers of packaging, are facing:	– Possibility that engineers and chemists may be required to redesign products to reduce costs under EPR frameworks – Requirements to reengineer packaging to achieve full recyclability and low toxicity in the environment – Requirements to redesign applications to increase the use of recycled material
Designers of packaging, including marketing/branding needs (sometimes package design is part of an internal department of a product manufacturer), are facing:	– Being required to redesign campaigns with different materials and other changes due to mandated EPR for their clients and vendors – Public accountability expectations that their client and their company are committed to minimal and fully recyclable packaging

(continued)

Table 4 (continued)

Interest group	External pressure
Consumer product companies who are the most public face of disposable plastic users (e.g., Starbucks, Coca-Cola, Pepsi, Nestle) are being forced to act because:	– There is demand for better product design to avoid negative public perception or other harm to the brand – Consumers are confronting companies that don't seem to be meeting their commitments to identify alternative materials or increased recyclability – Some companies are investing in plastic recycling companies to support plastics reuse (e.g., IKEA) and improve their capacity to comply with legislative changes
Product buyers (i.e., the consuming public) are changing behaviors because of:	– Increasing awareness of plastic pollution in waterways and oceans – Growing concern about the impact of single-use plastics (and its production) on community health – Public support for product bans, substitutions, and limitations has helped force changes in the law – New laws that have limited availability of certain products such as plastic bags
Municipalities, states, regions, SIDS (and private waste management companies) are responding because of:	– Pressure to reduce the significant costs accrue to municipalities from plastics in the environment – Public pressure to pass product bans to reduce the absolute volume of plastic – Increased responsibility for preventing plastics from becoming pollution via solid waste management solutions – Opportunities to generate positive economic activity from fully recyclable waste streams, especially plastics

(d) *Adaptive recycling and reuse as consumer products* must still prioritize necessity, safety, and end of life.
(e) *Mechanical recycling* into consumer products must consider necessity, safety, and end of life.
(f) *Waste-to-energy technology* must be cost-effective, not pollute air or water, and safe disposal of toxic ash must be considered.

Considering *food safety* means safety in every setting. Individual polymers may be "food safe" when used alone, but not when combined with other polymers, even if all combined polymers are also individually considered food safe. Recycled plastics must be proven to be as food safe as virgin plastic. Thus, polymers and polymer blends used in food packaging and storage products must each be tested separately for food safety in all logical potential conditions. This would include, but not be limited to, extreme heat in transport, use in microwave ovens, storage in extreme

cold (in a home freezer), and prolonged exposure to temperatures above 22°C, such as in the tropics. Equally as important, any "accidental additives" created in the blending process must be tested for food safety separately [76, 77].

As for *virgin polymers*, full reusability and true recyclability require any polymer to be chemically able to return to the original form given access to the appropriate technology. Technology must be accessible to developing nations and poorer communities to process any imported ingredients and products to fulfill the intent of the Basel Convention on plastic waste [18].

Producer responsibility incentivizes participation in solutions. Scientists studying smaller pieces and microplastics found in fish and seabirds can identify whether they originate from fishing rope, textiles, tires, cosmetics, or plastic bags – aiding policymakers in mapping sources and identifying potential interventions. Where plastic accumulates in the ocean and on beaches, the sources are often readily identified and can be traced. The brands are visible on many plastic bags, soft drink, and water bottles collected during the annual International Coastal Cleanup, which takes place in more than 100 countries each year [67]. Fishing gear is one significant category of ocean plastics that could be reduced through better design, monitoring, and enforcement. The US marine debris program works with fishermen to identify lost gear and remove it [78].

Some companies and communities have sought out plastic waste for *adaptive recycling and reuse*. Entrepreneurs are using waste plastics to make jewelry, shoes, shopping bags, and furniture. Their manufacturer should still consider how the product can be recycled. Likewise, the *mechanical recycling* of plastic bottles and bags into new consumer products such as carpeting and clothing must consider potential harmful consequences. For example, clothing made from recycled plastics such as fleece jackets are a significant source of microfibers in aquatic environments [79] and, in turn, are being found in shellfish and in the stomachs of fish and other aquatic life [80].

Finally, *waste to energy* has been posited as a solution to plastic (and other) waste that is already in landfills (or is being generated) in places where both energy and recycling technology are limited. In current use, waste to energy plants are extremely expensive, are not always adequately monitored for polluting emissions, and demand a continuing volume of waste over a long period to repay investment [81]. Thus, waste to energy has to be seen as a bridge technology, a last resort, and has to be affordable, safe, and intended to take care of the backlog of nonrecyclable materials found in landfills that are at risk of erosion into the sea. It has the most potential as a true solution in island communities or remote coastal areas to replace burning fossil fuel for energy production and where other ways to get rid of all waste are not feasible.

3.7 Establishing Priorities Through a Plastic Hierarchy

It is the remit of a national government to seek ways to reduce or prevent harm to the environment and human health. For plastics, this requires legislative action, especially to align Mexico with best practices from around the world, especially the most forward-thinking, comprehensive legislation regarding the manufacture and life cycle of plastics. The vision of such legislation is to ensure that when selling a plastic product, the producer must affirmatively show that plastic is *essential* and that there is no substitute or alternative product, nor alternative material from which to make the product. Establishing a plastic hierarchy in legislation helps standardize societal values about which plastics are beneficial to society and which are unnecessary and harmful.

Plastic hierarchy categories should include outright bans, use, or application limitations and some clear definitions of essential needs, based on a realistic timetable for redesign. For example, the European Union's initial regulations focus on regulating ten types of plastics that are most common in marine litter [58, 64]. Those regulations can serve as a template for part of a proactive legislative framework in Mexico as well. Truly effective national legislation will need to include the following:

1. National legislation should set forth outright bans of three types of plastic:
   (a) *Pointless or unnecessary plastic:* Plastic, which is not needed for sanitary, health, or safety reasons
      - *Examples:* Styrofoam (polystyrene) in any form, plastic wrap on individual fruit, plastic padding in shipping boxes, shrink-wrap as a marketing ploy, etc.
   (b) *Replaceable or avoidable plastic:* Anything for which an alternative that is fully reusable, recyclable, and/or degradable (with a circular economy in mind) exists
      - *Examples:* Single-use applications – straws, cigarette butts, shopping bags, drink containers, kitchen storage, etc.
   (c) *Problematic plastic:* Polymers and/or additives that are not easily recyclable and/or are inherently hazardous
2. *National legislation should define the plastics we need* and establish timelines for reengineering plastics or identifying and incorporating good substitutes into commerce and lacking those options, post-use disposal mandates, and responsibility:
   (a) *Hard-to-replace plastic uses:* These plastic products provide a valuable function over a long period and do not have equally appropriate substitutes or alternatives. Their production should be *strictly limited for purpose*, and it

should be a goal to ensure that these items have the most recycled content that is possible.

(b) *Essential plastic products or applications:* The plastics used in medical applications, for community health, or in extreme situations such as epidemics or natural disasters should be tested for human safety under realistic circumstances and be readily recyclable.

(c) *Balance of benefit to society:* Requiring the polymers used to be fully recyclable and safe for human health during and after use, even for such plastics as the lightweight components that improve transportation efficiencies. We must expand the principle of extended producer responsibility (EPR) to all plastic production so the benefits to society outweigh the costs.

Designing the hierarchy and the legislative mechanisms to implement it should result in legislation that is flexible enough to incorporate new technologies and products, but precautionary enough to limit the entry of products that are no better than what was in use. Timelines need to take into account products that have proven to be particularly challenging to reengineer such as bus, truck, tractor, automobile, and bicycle tires.

Tires are a relatively short-lived product that are essential to society while in use and mostly a waste management problem when no longer in use. The scale of the problem in Mexico is considerable. It is estimated that the state of Baja California alone disposes of 1–1.5 million tires each year, about a third of which comes from the United States. [82]. Mexican law already establishes responsibility for tire disposal and imposes a fee for each tire, so the solution is about enforcement and engaging manufacturers in redesign [82].

Tires continuously pollute waterways while in use because they continuously shed small pieces [7]. Thus, they must be reengineered to ensure that the particles shed are not toxic and the maximum possible percentage of the tire is fully recyclable. As part of an overall national legislative effort to improve plastics and limit future plastic pollution in Mexico's waterways, the issue of tires polluting waterways while in use would also need to be addressed. A legal extension of that existing precedent, as well as full-extended producer responsibility principles to all plastics, should also be incorporated into national law. Producers, retailers, and distributors need to take responsibility for the full life cycle of their materials. This is partly because municipalities "no longer want to subsidize increased waste management fees due to the proliferation of over-packaged and poorly designed products" [83].

3.8 Social and Economic Benefits from Rethinking Plastics

There are benefits to be embraced in the redesign of plastics. What is currently seen as waste could instead be viewed as a resource to be reused. Reapplying the same genius that went into designing plastics for their myriad of applications to redesigning them will generate opportunities for new kinds of recycling and other

businesses. Reducing the production of the kinds of single-use plastics that show up as waste on beaches and in waterways will improve visitor perception and community health. Likewise, there are public health benefits to ensuring that plastics are safe and fully recyclable.

Mexico can write policies and regulations to guide manufacturers toward a production-based approach to this global problem. By focusing on production before plastics reach the end user, any country can prevent its waste in the first place, allowing true reuse, instead of continuing to fill landfills because there is insufficient capacity to recycle or reuse. National legislation can help municipal governments draft acquisition requirements to create or improve markets. Preparing the country for these opportunities means asking and answering key questions: What are the recycling capacity gaps, what are the replicable strategies, and how can Mexico incentivize keeping waste management local?

Through legislative incentives to support circular economy solutions, plastic producers can become *part of the solution*. The European Union's Strategy for Plastics in a Circular Economy (January 2018) establishes a set of goals for national plans:

> To protect the environment and citizens from plastic pollution and to demonstrate the business case for transforming the way that products are designed, produced, used, and recycled. Under the new plans, all plastic packaging on the EU market will be recyclable by 2030, the consumption of single-use plastics will be reduced, and the intentional use of microplastics will be restricted. **The strategy highlights the main commitments for action at the EU level but also emphasizes the important role of businesses, together with national and regional authorities, and citizens.** [84]

The production and use of plastics are a big business. Redesign, recycling, and reclamation of waste plastics could be a big business too. Producers, users, and consumers each have a role to play in ensuring that the vast majority of plastic use is necessary and beneficial and that those products do not become a waste problem for future generations.

4 Conclusion

Plastic pollution in waterways is a global problem with significant local effects. As noted, plastic pollution has negative economic, social, and public health effects that do not decompose over time. Enhancing Mexico's management of this problem through legislation must address three challenges: (1) overlapping or unclear jurisdictional responsibility; (2) prevention of plastics entering waterways; and (3) incorporating the appropriate use and reuse of plastics into Mexico's sustainable development goals.

By law in Mexico, plastic pollution is subject to prescribed prevention. A truly comprehensive prevention strategy requires changing what is in the stream of commerce to *avoid convenience translating into pollution*. It also requires replacing the state-by-state piecemeal plastic bans and limitations, with a preemptive federal

law that would establish consistent standards across all states and municipalities and establish a template on which states and municipalities could model their own regulations, along clear jurisdictional lines.

Prevention has three strategies: (1) eliminating the production and sale of unnecessary plastics that are most likely to be found in waterways; (2) supporting community-based efforts to capture those large plastics that have found their way into the environment and providing their safe disposal (or recycling); and (3) getting to the root cause of plastic pollution, which is the failure to instill extended producer responsibility values in polymer design, use, and disposal.

National legislation would offer a common approach, weigh the benefit of specific uses, phase out replaceable and problematic (mostly single-use) plastic products, and introduce a rational approach to the plastics that add value to society. The strategy would also consider and incentivize collection and containment (and ultimately recycling) of plastics already in the environment. The goal is to connect plastic producers with the outcome and consequences of the manufacturing process and engage them in the process.

For the plastic already present in the environment and on its way to it, and for which there is not yet extended producer responsibility, it is a government's responsibility to address the health and safety of people and the natural resources upon which they depend. Thus, invigorating markets for recycling can, and should, be a temporary government function where a consistent legal framework enables private entities to invest in capacity based on predictable demand. To get past theory, the national government can provide financial assistance for the acquisition of recycling equipment by the appropriate authorities, better stormwater management technologies, and related support for research and development. Likewise, the federal government investment in technological capacity can help local entities respond to emerging sources of aquatic pollution such as eroding landfills due to sea level rise and unprecedented flooding.

The use and disposal of plastics remain a global challenge shared by all nations, as does addressing the cleanup of the millions of tons of plastic at risk of ending up in our waterways and ocean. The government and industry must collaborate in exploring innovative approaches that solve future plastic waste challenges. A national legislative approach sets parameters for manufacturers and must include a combination of public safety requirements, technology development, and tax policy tools. Mexico has a good constitutional and legal framework from which to build a national legislative strategy that is effective, proactive, and beneficial to the nation's health and well-being.

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The Problem of Microplastics and Regulatory Strategies in Italy

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Contents

Abstract The term "microplastics" was first used in 2004 to describe very small fragments of plastic (~50 μm) in the water column and in sediments. In 2009, Arthur et al. (Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris, Sep 9–11, 2008. NOAA Technical Memorandum NOS-OR&R-30. 49 p, 2009) proposed that microplastics should include all fragments <5 mm. Over the past decade, microplastic debris in both marine and freshwater systems has become an emerging environmental issue. Currently, the topic of microplastics is regulated at the European level only in the marine environment with the Marine Strategy Framework Directive (MSFD), ignoring that a very high percentage of microplastics that reach the sea come from inland waters and are closely connected with consumption styles. Recently, the Italian Parliament has adopted a proposal of the Italian NGO Marevivo to forbid microbeads scrub particles in cosmetics

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as of 2020. In addition, Italy has been the first country in the world to ban plastic non-biodegradable cotton buds as of 1 January 2019. In this way, the excellence of the Italian cosmetic industry focuses on the environment and on sustainability: an example that we hope will be emulated in other sectors. Although 70–95% of the marine litter, including microplastics, comes from the land environment, studies of microplastics in freshwater systems are limited in comparison to those focused on marine habitats. Rivers and inland waters are responsible for microplastics transport to marine habitats and could represent a vector for the downstream transport of pollutants suggesting an overlooked and potentially significant component of the global microplastics life cycle. In this frame, the MICROPLASMA (MIcro and maCRO PLAStic pollution Monitoring with Advanced technologies) research project funded by Apulia region aims to set up an integrated and innovative monitoring system along an urban river located in South Italy focusing on the seasonal and spatial trends of plastic wastes.

Keywords Freshwaters monitoring, Microplastics, Pollutants, Regulation

1 Introduction

Anthropogenic debris is a growing environmental concern, whose implications are not yet thoroughly understood despite its global importance. In recent years, the role of plastics as the primary component of anthropogenic debris has come to the attention of the scientific community [1], and the ubiquity and potential effects of plastic debris are recently being disseminated to the wider public and government bodies considering plastics as one of the indicators of the Anthropocene [2].

Plastics are considered a top environmental problem [3, 4] and are identified, alongside climate change, as an emerging issue that might affect human ability to conserve biological diversity in the near to medium-term future [5].

Plastic debris items, ranging in size from microscopic to items meters in size, are found in benthic and pelagic habitats in all oceans and in remote locations such as the Arctic, Southern Ocean, and the deep sea [6–10].

According to the data from Plastics Europe [11], production of plastics begins in earnest in the 1940s and 1950s and increased from 5 tons in 1950 to 348 million tons in 2017 (representing a compound annual growth rate (CAGR) from 1950 to 2015 of about 8.6%), and it is estimated that it will reach 400 million tons by 2050. China is the largest producer of plastic materials (only thermoplastics and polyurethanes), followed by Europe and NAFTA (North American Free Trade Agreement). Among the major producers of plastics in Europe, Italy is located at the second place, contributing to 14% of the total European plastic converter demand [11].

Located in the middle of the Mediterranean Sea, which is known to have the highest amount of municipal waste annually generated per person (491 kg/year [12]) and it is now widely recognized as one of the most affected areas in the world by plastic pollution [13–15], Italy is also subjected to influences and inputs of plastic waste that come from this sea.

The Mediterranean Sea, in turn, being surrounded by a large number of industrialized countries, traversed by numerous busy shipping lanes, and characterized by a net inflow of surface waters of Atlantic origin through the Strait of Gibraltar, with no outflow possibility for items less dense than seawater anywhere, is particularly vulnerable to this form of pollution [16, 17]. Indeed, large-scale surveys by Suaria et al. [14] show some of the highest concentrations of floating plastics to occur in the Mediterranean Sea. It is estimated that it is the sixth biggest accumulation zone of marine litter in the world [14].

Recent studies [14] demonstrated the pervasiveness of plastic pollution in Mediterranean waters confirming model predictions and providing further evidence about microplastics (MPs, plastic fragments <5 mm) abundances in this basin that were found to be among the highest in the world.

Sinks, sources, fate, and residence times of macroplastics and MPs are the main knowledge gaps to be addressed, especially with regard to the smaller size classes. In this context, rivers could represent an overlooked and potentially significant component of the global plastic life cycle acting as a source and vector of plastic waste and transferring plastics from land to the marine environment. Indeed, it is well-known that approximately 70–95% of the marine litter including MPs originates from land-based sources [18].

Until recently, the main research on plastic pollution has focused on the marine environment and less than 4% of publications had a freshwater context [19]. This has started to change in recent years, and attention has now also been directed toward both the terrestrial [20, 21] and freshwater environments [21–23]. Monitoring studies have quantified microscopic plastics debris, so-called MPs, in freshwater systems, including riverine beaches, surface waters, and sediments of rivers, lakes, and reservoirs (e.g., [24, 25]). Although far less data is available compared to marine systems, these studies highlight that MPs are ubiquitous and concentrations are comparable to the marine environment [26].

There is considerable complexity involved to understand the impact of these synthetic materials on the natural world due to their heterogeneous physicochemical properties that make MPs a multifaceted stressor. All MPs are expected to fragment continuously in the environment on unknown timescales, reaching nano sizes (<1 μm) [27]. However, we have a poor understanding of degradation rates of fragmentation, and this is of concern because the spread and abundance of MPs are increasing [9, 28].

2 Legislation and Regulation About Plastics

2.1 European Strategies

Legal frameworks, set up across international boundaries, such as MARPOL 73/78 [29] International Environmental Convention, the European Union's Water Framework Directive (Directive 2000/60/EC) [30], and the European Marine Strategy

Framework Directive (Directive 2008/56/EC) [31], promote integrated management of freshwaters and marine waters, and part of this management involves addressing pollution including materials in suspension such as floating waste and MPs [13].

MARPOL 73/78, the International Convention for the Prevention of Pollution from Ships, which entered into force on December 31, 1988, is considered one of the most important in terms of pollution prevention caused by maritime waste, hydrocarbons, and discharge released by ships.

As of January 2018, 156 states worldwide are members of the convention. Annex V contains the rules to reduce pollution from solid waste, a potential lethal harm for marine life like oils and chemical products, and defines plastic materials, macro and micro, as the most dangerous due to their floating capacity and the possibility of being confused by marine fish and mammals as a food source. It also forbids the discharge of plastics anywhere at sea and provides strict restrictions for the spread of other solid waste into the sea in coastal areas and special areas (in which, for technical reasons relating to their oceanographical and ecological condition and to their sea traffic, the adoption of special mandatory methods for the prevention of sea pollution is required, e.g., Mediterranean Sea, Baltic Sea, Black Sea, etc.).

The Marine Strategy Framework Directive (MSFD) establishes the framework for Member States to achieve a Good Environmental Status (GES) by 2020 for their marine waters. "Good environmental status" means the ability to preserve ecological diversity and to secure sustainable development of marine resources considering 11 descriptors. Descriptor 10 focuses on marine litter, including (micro)plastics, stating that GES is achieved only when "properties and quantities of marine litter (i) do not cause harm to marine life and habitats, (ii) do not pose direct or indirect risks to human health, and (iii) do not lead to negative socio-economic impacts." Indeed, descriptor 10 requires to obtain information on "Trends in the quantity, distribution and, if possible, in the composition of microparticles (in particular microplastics)" [31].

Recently, in December 2015, the European Commission identified plastic management as a key priority and adopted an EU Action Plan for a circular economy taking into account the entire plastic life cycle.

On January 16, 2018, the first-ever Europe-wide Plastics Strategy laid the basis for a new and sustainable plastics economy aimed to protect the environment from plastic pollution while at the same time promoting economic growth and innovation.

The aim is that all plastic packaging on the EU market will be recyclable or reusable by 2030. The consumption of single-use plastics will be reduced or forbidden. Producers will have to contribute to cover the costs of management and remediation of waste as well as the costs of sensitization measures for some products. The design and production of plastics and plastic products will respect reuse, repair, and recycling needs, and the intentional use of MPs will be limited.

In order to achieve these objectives, the new rules of the European Commission include:

- Plastic ban on some disposable products: where alternatives are available and accessible, disposable plastic products will be banned from the market. Plastic disposable beverage containers will be allowed on the market only if their caps and lids remain attached.
- Consumption reduction targets: Member States will have to reduce the use of plastic containers for food and beverage glasses, setting national reduction targets.
- Obligations for producers: producers will contribute to cover waste management and cleaning costs, as well as awareness measures for disposal of food containers and packages (such as for potato chips and sweets), beverage and cup containers, tobacco products with filters (like cigarette butts), wet wipes, balloons, and light plastic bags. Industry will also receive incentives to develop less polluting alternatives for these products.
- Collection targets: Member States will be obliged to collect 90% of plastic bottles for single-use drinks by 2025, for example, through deposit-refund systems.
- Labeling requirements: some products will have clear and standardized labeling in order to provide information on how waste should be disposed of, on the negative environmental impact of the product, and on the presence of plastics in products.
- Awareness-raising measures: awareness campaigns, measures to prevent waste littering, and projects to clean up beaches could be set up by public authorities and could receive EU funds, for instance, through the European Solidarity Corps. Member States will also be obliged to raise consumer awareness of the negative impact of disposable plastic waste and fishing gear, as well as the available reuse systems and waste management options for all these products.

Regarding reduction of waste discharged by ships, the European Commission is presenting a legislative proposal on port reception facilities aimed to ensure that waste generated on ships or gathered at sea is delivered on land and adequately managed. Building on this, the Commission will also develop target measures to reduce the loss of fishing gears at sea examining, at the same time, the contribution of aquaculture to marine litter studying a range of measures to minimize plastic loss by aquaculture.

With regard to MPs intentionally added to commercial products (such as scrubbers or microbeads in cleaning and cosmetic products), several countries have already taken action to restrict their use, while the cosmetic industry has also taken voluntary action. Bans are under consideration or planned in several Member States, and this may lead to fragmentation in the single market. In line with the REACH[1] procedures for restricting substances that pose a risk to the environment or health, the Commission has therefore started the process to restrict the use of intentionally added MPs, by requesting the European Chemicals Agency to review the scientific basis for taking regulatory action at the EU level. The Commission will also consider

[1]REACH = *R*egistration, *E*valuation, *A*uthorisation and Restriction of *Ch*emicals, Regulation (EC) No 1907/2006.

measures such as labeling and better information and minimum requirements on the release of microfibers from textiles, as well as measures to reduce plastic pellet losses.

Authors investigating MPs [18, 19, 25, 32] in aquatic ecosystems have noted that microplastic debris is also abundant in rivers and lakes as a result of terrestrial human activities involved in the usage of plastics considering thus freshwater environments as an important source and transport pathways of MPs to the ocean.

However, despite this awareness, the microplastic issue is regulated at European level only in the marine context. MPs' presence in freshwaters has recently received attention from the scientific community. Policy initiatives are thus less developed than for marine systems but could benefit from similar initiatives to those of Europe's MSFD and the activities of the US IMDCC (The Interagency Marine Debris Coordinating Committee).

2.2 Italian Regulation

Although not all European directives related to environmental issues have been implemented in time by Italy, it was among the first countries to engage in the protection of water basins from pollution, especially that one related to plastics. In addition to numerous European directives and international conventions, Italy has implemented several national instruments against plastic pollution.

As an example, the "Environmental Law to promote green economy measures and to contain excessive use of natural resources" of December 28, 2015, has promoted transition to a circular economy with several actions such as regulation for the selection of ports with suitable sites for the collection of waste taken during sea activities, encouraging recycling and separate collection. This law also promotes awareness campaigns and introduces sanctions for those who abandon waste in the environment.

Recently, after a long bureaucratic process, the Italian Parliament has introduced new provisions on the marketing of plastic bags, approving the "Mezzogiorno" Decree [33], which, incorporating and implementing the European Directive no. 720 of 2015 [34], has introduced (starting from January 1, 2018) the obligation to use only biodegradable bags for fruit and vegetables that must strictly meet certain technical requirements certified by accredited bodies.

On May 23, 2016, the Italian NGO (non-governmental organization) Marevivo proposed a law at the Italian Parliament, demanding a complete ban concerning the use of MPs in cosmetic products. The proposal, supported by about 100 parliamentarians, was approved by the Italian Parliament by an amendment to the 2018 Budget Law, and it forbids both the production and the sale of care products and cosmetics with MPs by 2020.

It is not viable to remove MPs from habitats due to their small size and their continuous evolution via the breakdown of larger items. Hence, measures focused on reducing inputs are widely recognized as being the most effective. However, even if

we were able to completely stop inputs of debris to the environment, the quantity of MPs would likely increase because of fragmentation of larger plastic items already in the environment and legacy inputs of MPs.

In a monitoring study [35] conducted by ENEA Institute (National Agency for New Technologies, Energy and Sustainable Economic Development) and the NGO Legambiente, everyday pollutants were examined on Italian beaches. Thereby it has become evident that everyday pollutants, such as cotton buds, are spreading on Italian beaches (nearly 7,000 cotton buds [35] were found on 93 Italian beaches representing 7.4% of the total waste found) [35] and are contributing heavily to plastic pollution. The leading cause of this phenomenon is the usage of toilets instead of rubbish bins for their disposal. For this reason, Italy approved the most cutting-edge legislation in Europe: it was the first country in the world which prohibited the marketing and manufacture of non-biodegradable cotton buds in Italy as from January 1, 2019. The new rules [36] provide for the obligation to use ear-cleaning sticks made of biodegradable and compostable material, prohibiting the production and sale of those with plastic supports. On the packaging manufacturers will also need to provide clear information on the correct disposal of the sticks themselves, explicitly mentioning the ban on throwing them into toilets and drains.

Moreover, starting from May 1, 2018, trade union orders have been issued in several Italian municipalities which ban disposable tableware, which is not compostable. Although there is no explicit legislative prohibition to use and market non-compostable tableware, the choice of several municipalities to exclude their use was determined by the need to reduce undifferentiated waste, pollution of the seas, and management costs and to increase percentage of separate collection.

In line with the Europe-wide Plastics Strategy, considering the constant increase of plastic waste in the Mediterranean Sea [15] and the consequent damages, recently various legislative proposals have been presented to the Italian government in order to achieve ever more ambitious targets to reduce plastic waste. These include proposals to restrict non-biodegradable plastic production, to prohibit products such as helium-filled rubber balloons, measures for the limitation of the use of plastic objects on beaches and other natural areas, and measures aimed to collect plastic waste dispersed at sea and in inland waters.

On October 2018, the Italian Minister of Environment, Sergio Costa, launched the Plastic Free Challenge campaign, which aims to eliminate and reduce the disposable plastic, involving more people from companies to institutions.

Planned actions include installation of natural or sparkling water dispensers, free distribution of aluminum bottles, substitution of plastic cups with those of paper in the dispensers of hot drinks and plastic spoons to stir coffee with those of wood, limitation in the use of products with excessive packaging, elimination of straws, use of canvas bags instead of plastic ones, and finally replacement of plastic films to store food with reusable containers. Citizens' awareness campaigns and professional refresher courses for communication operators will also be promoted. The City Council of Milan and the National Council of Research have joined the Plastic Free campaign in favor of biodegradable products. From the Chamber of Deputies to the Ministry of Economic Development, from universities to research institutes, the list of the members of the Plastic Free campaign is getting longer and longer.

3 Monitoring MPs in Freshwater Environments: Major Issues and Short Overview of Methodological Approaches

Surveys about MPs strongly depend on the adoption of an appropriate methodological approach. Sampling to characterization is considered as a new challenge for analytical scientists [32, 37, 38]. The small size of MPs complicates their extraction from environmental matrices and their consequent quantification. Therefore, increasingly more sophisticated approaches and modern analytical instruments are required. Furthermore, MPs are heterogeneously distributed in freshwater environments like rivers and lakes, both horizontally and vertically in the aquatic compartment. Thus, the location of sampling and the number of samples replicates is of high importance in order to reduce environmental variability. MPs distribution is not homogeneous due to several factors related to their input sources but also due to their movement and transport within the water body that is governed by its hydrology (e.g., flow conditions, daily discharge) and its morphology (e.g., vegetation pattern) [19, 39] as well as due to their physicochemical properties like their density and the formation of biofilms. Therefore, sample from the same point at various time intervals could be a useful strategy in sampling a river.

Sources of plastic debris in freshwater systems have not been studied extensively but likely include effluents from wastewater treatment plants (WWTP), sewage sludge, shipping activities, atmospheric fallout, direct disposal from the public, beach littering, and runoff from agricultural, recreational, industrial, and urban areas [22, 40]. The great variety and complexity of MPs input in aquatic compartments reflect a wide spatial and temporal variability of MPs abundance in the environment that translates in a lack of reproducibility in samples. Therefore, in order to reduce variability of samples, replicates in space (e.g., at the center of the riverbed, on the right bank, on the left bank) and time (in different time slots, e.g., at the morning, in the afternoon, and at the evening) are greatly suggested.

The freshwater environment contains many particles of organic and inorganic origin (e.g., leaves, pieces of wood, flowers, pollen, sediment, minerals, etc.) that strongly interfere with the extraction and separation of MPs from the environmental matrix and their consequent detection. Therefore, suitable methods for the sample preparation are needed in order to remove natural organic debris that interpose to quantification and characterization analysis. The purification step turns out to be the most complicated; a variety of cleaning treatments have been proposed recently to digest organic matter (wet peroxide oxidation, acid and enzymatic digestion). At the moment, there is no method that allows a removal of 100% of the natural component with a recovery of 100% of the synthetic particles [32, 41, 42].

Once the particles are separated from the matrix, quantification requires weighing or counting. This is a very difficult task, especially for particles that are barely visible to the eye. Therefore the use of a microscope is required (visual sorting). However, counting and characterization of particles only by using a microscope present a high risk of overestimation due to large quantities of substances of natural origin still present in the extracts [43]. Hence, further chemical identification of MPs is

indispensable since several studies state that up to 70% of the particles visually identified are false positives after chemical characterization [38, 44]. Therefore, an analytical method to confirm the synthetic polymer origin of potential MPs particles is mandatory especially for smaller items (<500 μm) as the probability of misidentification is very high. Moreover, due to a large variety of polymers (more than 5,000), characterization of their chemical composition is of basic importance in order to ensure the accuracy of collected pollution data and to determine their distribution and impact in the environment [43].

In order to identify both large (>500 μm) and small (<500 μm) MPs in environmental samples, the use of spectroscopy as nondestructive identification technique is strongly recommended FT-IR spectroscopy, near-infrared spectroscopy, and Raman spectroscopy). It can determine the chemical composition of unknown plastic fragments with high reliability when comparing the IR spectrum of an unknown plastic sample with spectra of known polymers. These techniques are able to identify certain polymer types at a resolution from about 10 μm (IR) to 0.5 μm (Raman, 532-nm laser and a _100 objective).

Large particles can easily be analyzed by an FT-IR surface technique ("attenuated total reflectance" (ATR) FT-IR spectroscopy) at high accuracy in less than 1 min providing further information on physicochemical weathering of sampled plastic particles by detecting the intensity of oxidation [45]. Coupled to microscopy "micro"-spectroscopy (μ-ATR-FTIR) allows the analysis of microscopic particles and their clear assignment to polymer origin. In this context, the use of two measuring modes is feasible: reflectance and transmittance. Unfortunately, this approach is very time-consuming, since the ATR crystal has to be focused on each single particle. Thus, only 25% of the whole filtered area was measured [46].

Major disadvantages of these methods are the time-consuming scanning procedure, the measurement of irregularly shaped microplastic particles present in environmental samples that may result in un-interpretable spectra as a result of refractive errors [47], the lack of information about associated organic additives to MPs, and the overlap of polymer bands given by organic and inorganic contaminations that can disturb identification of particles [48].

Therefore, these methods are obviously difficult to implement as routine analysis [49], even if the new generation tools are becoming more and more performing and focused for MPs analysis, reducing time and improving performance, yet have a high cost factor.

Fundamentally different analytical approaches to identify MPs in environmental samples are destructive thermoanalytical methods like pyrolysis gas chromatography in combination with mass spectrometry (Py-GC/MS) that use pyrolysis to break polymers into smaller moieties, of which the characteristic volatile degradation products are then separated and identified using GC/MS and can be traced back to their precursor polymers [50].

Disadvantages of Py-GC/MS with regard to spectroscopy techniques are on the one hand that the particle is not available anymore after the analysis for further investigations and on the other hand longer acquisition times for each item respect spectroscopy (about 30 min for one Py-GC/MS run respect 1 min for one FTIR

spectrum). Moreover, this approach is size limited (~50/100 μm), and it has the drawback that particles have to be manually placed into the pyrolysis tube [51]. Since only particles of a certain minimum size can be manipulated manually, this results in a lower size limitation of particles that can be analyzed. Furthermore, the technique allows only for the analysis of one particle per run and is thus not suitable for processing large sample quantities, which are collected during sampling campaigns or routine monitoring programs [46].

However, the main advantages of using Pyr-GC/MS over commonly applied FT-IR or Raman spectroscopy are that the measurement is independent of shape of particles, inorganic contaminations do not disturb the identification, the technique gives detailed information about the chemical nature of the polymer, and contained organic additives can be achieved simultaneously in one run. Polymers contain plastic additives (PAs) to modify the color (pigments and dyestuffs), to improve or modify mechanical properties (fillers and reinforcements), to provide resistance to heat and aging (antioxidants and stabilizers), to provide resistance to light degradation (UV stabilizers), to improve flame resistance (flame retardants) and processing characteristics (recycling additive), and to improve the performance (antistatic/conductive additives, plasticizers, blowing agents, lubricants, mold release agents, surfactants, preservatives) of the polymer. Plastic products and their fragments generally contain a large amount of additives or unreacted raw materials that can leach into the surrounding environment during their use or their disposal. Many of these compounds (e.g., phthalates, polybrominated diphenyl ethers, bisphenol A) are persistent molecules which can be hormone-disturbing, reprotoxic, or even suspected carcinogenic [52–54], and they have been investigated for their effects on the environment and human health.

One of the main problems related to MPs is the fact that there are no agreed monitoring methodologies at international level. Guidance on the monitoring of riverine macro- and microlitter is needed, including adoption of universal criteria for sampling and reporting MPs units to facilitate comparison of data. In order to quantify riverine litter input to the marine environment, monitoring methods have to provide data that can be related to the river flow in order to be able to calculate litter fluxes (e.g., visual observation of the river water surface and collection method for the river water body).

At national level in Italy, agreed monitoring and sampling methodologies exist only for the marine environment [55]. In this context, the Regional Agencies for Environmental Protection (ARPA), based on the delegation and commission of the Italian Regions, carried out a monitoring of MPs in the Italian Seas as part of activities planned at national level and financed by the Italian Ministry of the Environment and Protection of the Territory and the Sea (MATTM) in order to answer to the information requested by the MSFD on the specific topic. The standard protocols for monitoring, sampling, and sample preparation have been developed by ARPAs at regional level.

4 Monitoring Microplastics in River Ofanto

Within the MICROPLASMA (MIcro and maCRO PLAStic pollution Monitoring with Advanced technologies) project, a preliminary monitoring study of MPs in Ofanto, the biggest river of Apulia Region (Southern Italy), has been carried out [56]. Based on the first findings and the concerns of the scientific community, the activity aimed to expand the dataset of MPs pollution in Italy and to better understand its distribution, behavior, and impact in order to provide a future regulation plan. It focused primarily on the abundance, type, composition, and potential implications of MPs in an Italian river evaluating at the same time the presence of temporal trends in response to hydrological parameters (flow velocity, water level of river, and seasonal variability of water flows). Another aspect of the study is related to the identification and quantification of persistent organic pollutants adsorbed on MPs which then become vectors for these highly toxic pollutants, and therefore bioaccumulation and biomagnification in the food chain may occur posing a long-term risk to the environment. Some of these compounds are intentionally added during plastic manufacture to enhance the performance of plastic products (e.g., plasticizers, antioxidants, UV stabilizers, and flame retardants), while others – mainly persistent bioaccumulative toxic substances (PBTs) – are adsorbed from the surrounding ambient.

4.1 Methodological Approach

4.1.1 Step One: Experimental Design

Samples were collected from the Ofanto river, the largest river in Apulia Region (Italy) for length, area, and abundance of water. In order to monitor the trend of MPs concentrations over a year, five seasonal sampling campaigns have been planned. River surface MPs samples were collected in February, April, October, December 2017, and May 2018; all of them were taken from the same point located 6 km from the Ofanto river mouth ensuring sampling only of freshwater. In order to reduce the spatial variability, due to heterogeneous distribution of synthetic particles in a river, MPs were collected by three surface plankton nets (2.5 × 0.55 m) of 333-μm mesh size fixed in the middle of the river simultaneously (Figs. 1 and 2) during two different time slots (11:00–13:00 and 13:00–15:00) with a total of six replicates for each campaign (Table 1).

The net skimmed the surface with a part of it kept above water, sampling the upper 45 cm of the river surface layer. The part of the net submerged was monitored and recorded, and an effort was made to maintain a consistent submersion depth throughout the sample duration. The total volume of water filtered through the net was computed from the width and height of the submerged portion of the net, the sampling duration, and the average velocity of the river. Spraying the outside of the

Fig. 1 Sampling configuration adopted during campaigns

net washed the sampled material – plastics, biological debris, fine sediment, and other items – down into the detachable collector tube at the bottom of the net. Data about the weather condition (e.g., air temperature, recent precipitation, level, and flow of the river) were provided by Civil Protection (a governmental structure of the Italian Republic in charge of the coordination of activities on prediction, prevention, management, and overcoming of disasters, calamities, human and natural) for each day of the five sampling campaigns. An average daily water level and flow rate were calculated based on 48 observations per day (each 30 min); precipitation data were estimated as monthly precipitation accumulated in the reference month, intended as the 30 days preceding the sampling. Water quality parameters (e.g., surface water temperature, salinity, pH, conductibility) were recorded during each sampling campaign using a pH-meter and a conductibility probe.

4.1.2 Step Two: Laboratory Preparation of Samples

All samples were preserved in glass jars and processed using a method developed and supported by the National Oceanic and Atmospheric Administration that has been used in numerous published studies in the past few years. Material captured by trawl was separated through 5.0 mm and 0.3 mm stainless steel sieves using distilled water. Material retained on the 5.0 mm sieve was discarded, while material retained

Fig. 2 Plankton nets fixed in the middle of the river. Each net represents a sample replicate

Table 1 Experimental design for the five sampling campaigns with two samplings each

Sampling campaign	Sampling 1 11:00–13:00	Sampling 2 13:00–15:00
February 2017	3 replicates	3 replicates
April 2017	3 replicates	3 replicates
October 2017	3 replicates	3 replicates
December 2017	3 replicates	3 replicates
May 2018	3 replicates	3 replicates

Therefore, six replicates for each campaign have been collected
In total 30 samples have been gathered

on the 0.3 mm screen was placed in a 40°C drying oven for 24 h. After recording dry weights, each sample was divided into two subsamples (fraction A and B) (Fig. 3). Fraction A, used for pollutant analysis, was composed of the biggest plastic particles (5,000–2,000 μm) selected from the collected material and picked manually using forceps. The extracted microplastics were then placed in sterile plates and stored for chemical investigations. The remaining sample part (fraction B) earmarked for quantification and identification of MPs was subjected to chemical digestion (using 30% hydrogen peroxide in the presence of an iron (II) catalyst) in order to remove the labile organic matter and extract all particles. Plastic debris is resistant to this wet peroxide oxidation (WPO) processing.

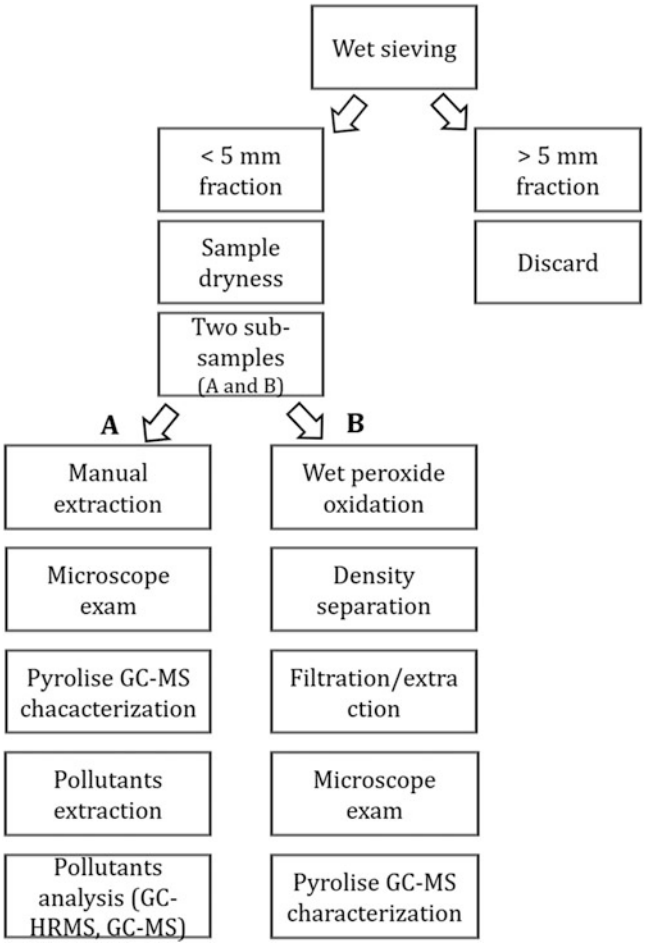

Fig. 3 Procedural steps to which the sample is subjected after the collection from the river

Samples then went through a salinity-based density separation using sodium chloride (with a density of 1.2 g/cm^3) where microplastics floated and heavier inorganic material was drained from the sample (Fig. 4). In order to enable higher-density polymers to be extracted, settled solids have been visually inspected for any MPs. If MPs were visually detected, they were removed using forceps.

After processing, the samples were filtered using a 0.45 μm mesh size, and all the particles were collected for visual identification (Fig. 5) under a 40× digital microscope (Keyance VH-Z 100 UR).

All microplastic particles visually identified were counted, photographed, enumerated, and categorized according to size (<500 μm, 500–1,000 μm, 2,000–1,000 μm, 5,000–2,000 μm), color (white, red, yellow, black, blue, green, transparent, and brown), and morphology as fragments and flakes (broken down

Fig. 4 Density separation of a MP sample

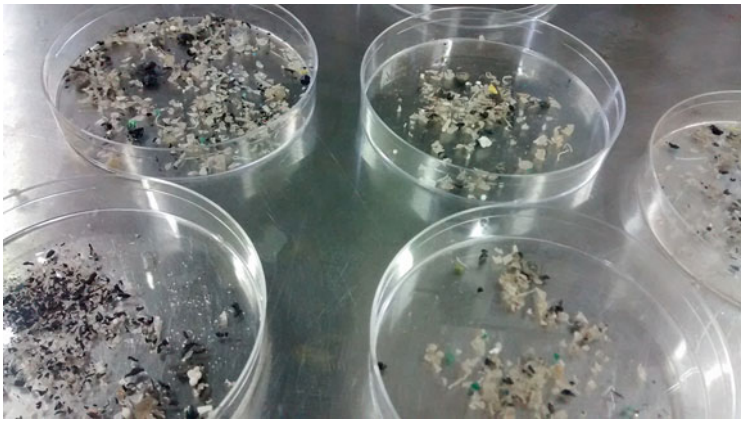

Fig. 5 MP particles extracted from samples

pieces of larger debris such as plastic bottles), pellets/spherules (preproduction pellets, microbeads from personal care products and bead blasting, and other spheroids), lines and fibers (particles of fishing line and nets and fibers from synthetic textiles), films (plastic bags and wrappers), or foams (foam cups, take-out containers, packaging) (Fig. 6).

Fig. 6 Categorization of microplastic particles by shape

4.1.3 Step Three: Quality Assurance and Quality Control

In order to prevent MPs contamination during the sample processing of fraction B, work surfaces and glassware were thoroughly washed three times with Milli-Q water and then dried before using; hands were thoroughly scrubbed prior to work commencing. All materials used during the study (forceps and glassware) were moved into a laminar flow cabinet directly afterward and covered with aluminum foils. When not in use, the material was washed thoroughly between trials.

Furthermore, the filtration unit was covered with watch glass during the whole filtration. The used filters were copiously rinsed with Milli-Q water. In order to avoid airborne contamination, work was carried out in a laminar flow cabinet, and the workspace was cleaned with a vacuum cleaner two times before working. During the whole study, 100% cotton clothing was worn, and sample preparation was performed with only one person per lab in order to avoid contamination. To estimate further contamination, two different types of blanks were conducted along with the samples: a process blank (a clean filter left out during all the purification and extraction process of MPs) and a lab blank (a clean filter left out for the duration of visual inspection at a microscope to collect any atmospheric MPs that may be present in the lab).

Only fibers (composed by about 50% of polyamide fibers and 50% cotton fibers), no fragments, flakes, lines, films, foams, or granules, were found in the blanks. The blank values were stable, which had an average of seven fibers per process blank and five fibers per lab blank. The fiber abundance reported in this study was corrected for the blanks.

5 MICROPLASMA Project

The MICROPLASMA project (MIcro and maCRO PLAStic pollution Monitoring with Advanced technologies) has been funded by the public announcement INNOLABS (acronym for Innovative Solutions for Problems of Social Relevance) of the Economic Development, Innovation, Education, Training and Labor Department of the Apulia Region, in the sector of Environment, Safety and Territorial Protection Smart City and Knowledge Community solution. It aims to implement an ongoing monitoring system of floating and beached plastics (micro and macro) along the Ofanto river, its banks, and at the mouth, through the creation of a MPs sampler prototype and the application of image processing methodologies to data acquired by remote sensing techniques. The system will provide information to an expert system, based on machine learning algorithms that will be able to support decision-makers and to predict, to a certain degree of reliability, the trends of the monitored parameters.

The chosen area is located in an important ecosystem, and its main naturalistic value closely coincides with the Ofanto river course. Along the entire fluvial course, a SIC (Community Interest Site) area has been identified that has led to the establishment of a Regional Natural Park "River Ofanto" with Regional Law December 14, 2007, n. 37 [57]. However, the entire area is characterized by the strong presence of human beings attested by the large presence of vegetable gardens, by large areas (tourist villages) built in sensitive areas (e.g., with protected species) and by the transformation of coastal morphology. The environs of the mouth are also affected by pollution of river waters due to civil and industrial wastes, the use of large quantities of fertilizers that enter the Ofanto river, and the intense and abusive cultivation of the floodplain, especially at the terminal stretch of the river.

The presence of waste, for the largest part plastics (micro and macro), causes serious effects mainly related to their ability to adsorb various classes of chemical pollutants (such as pesticides, polychlorinated biphenyls, and hydrocarbons). These substances, poorly soluble in water, are hydrophobic and thus have a great affinity with plastic.

Therefore, rivers and inland waters could represent transport vectors of persistent organic contaminants becoming an important component of the MPs global cycle. Present regulations about monitoring of freshwater environments do not consider MPs, and its interactions with pollutants as an emerging and complex issue, underlining the need of a deepening and revision of the current legacy, focused only on the marine environments.

For this purpose, one or more innovative sampling protocols of the Ofanto river superficial water will be identified in order to correlate data about MPs abundance with data coming from real-time detection of water quality parameters (such as turbidity, level and flow of the river, nutrients, dissolved oxygen, etc.) acquired with multiparametric probes and data about floating macroplastics obtained by remote sensing techniques.

The relevant and significant information will flow into an ICT (Information and Communication Technologies) platform, which can, on the one hand, facilitate the collection and sharing of heterogeneous data concerning water quality and, on the other hand, reduce the gap between information and decision-making, as the latter will be supported by smart monitoring applications.

The sampler prototype and the smart monitoring system will be implemented by all beneficiaries of regional funding, i.e., the Water Research Institute of the Italian National Research Council (IRSA-CNR), and the companies SimNt, Thermofluid, and ETG.

Monitoring activities of macroplastics will be carried out using remote sensing techniques based both on hyperspectral airborne sensors (48 bands) and on reflex cameras with modified acquisition filters and mounted on drones. Moreover, monitoring will actively involve stakeholders (mainly citizens and environmental associations) using the citizen science approach that aims to monitor beached debris by the visual census methodology collecting different kinds of information associated with each macroplastic item (such as coordinates, size, typology, description, color, pictures, and videos) through the use of a smartphone application developed ad hoc that will send data to the server in real time.

Data collected and processed will feed a geo-database belonging to an ICT management platform with different levels of authorization access for the various subjects involved (administration, associations, citizens), built entirely with open source software and able to produce thematic maps with high temporal and spatial density (based on the support of available satellite images too) and trend curves of some parameters in order to represent an overview of the environmental situation in real time.

In addition, the project comprises specific tasks related to communication actions about technologies/applications developed through various tools including websites, software, smartphones and tablets apps, scientific publications in scientific journals, ebooks, workshops, seminars, and advertising campaigns. Through this set of strategies, the project aims to reach the following "recipients": Italian citizens, managing authorities, control bodies, media operators (radio, TV, journalists), associations, research institutions, and other organizations.

Finally, specific actions (e.g., demand of European patent, request of technology transfer), above all for what concerns the realization of the sampler prototype, are provided in order to protect the project's industrial results.

6 Conclusions

The European Commission has recently identified plastic as a key priority issue and adopted an EU Action Plan (Plastics Strategy) for a circular economy taking into account the entire plastic life cycle.

On national level, Italy has implemented several instruments against plastic pollution, being the first country in the world which forbids both the production

and the sale of care products and cosmetics with MPs by 2020 and to ban marketing and manufacture of non-biodegradable cotton buds in Italy as from January 1, 2019.

Macro- and microplastics have been investigated intensively in the last years with studies in the marine environment. Only recently, researchers also investigated freshwater environments.

The case study of MPs monitoring in the Ofanto river is the first work with an Italian river context, and it aims to propose a new methodological approach for MPs monitoring.

The approach used in the Ofanto river points to set a common monitoring scheme taken into account temporal and spatial variability in microplastics studies on freshwater environments.

Climatic features (e.g., river regime, storm and rain events, seasonality) and human activities (e.g., industrial wastewater, runoff from agricultural land, treated wastewater effluent discharges) are among the greatest factors that influence the microplastics concentration in freshwater environments.

Temporal variability is particularly important to define in order to identify the main drivers of microplastics. Frequent samples are suggested to detect diurnal variations (e.g., linked to domestic waste), seasonal variability (mostly in connection with climatic factors), and year-to-year trends (mostly due to human influence).

Moreover, the high spatial heterogeneity of microplastics distribution in freshwater environments implicates that only a fraction of this heterogeneity can be captured in a sample. Therefore, the spatial variability can be reduced only increasing the number of samples replicates. These will be used to estimate a spatially averaged value to calculate mean values of microplastics concentration.

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Concluding Remarks on the Role of Stakeholders in Addressing Plastic Pollution of the Aquatic Environment

Friederike Stock, Georg Reifferscheid, Nicole Brennholt, and Evgeniia Kostianaia

Contents

Abstract The second volume of the book "Plastics in the Aquatic Environment – Part II: Stakeholders' Role against Pollution" looks at the plastic pollution from the societal and policy points of view. The volume comprises 12 chapters giving an overview of mechanisms aiming at preventing or reducing plastic pollution. This chapter provides a brief summary of discussions and results of the research or projects reviewed in the chapters of this second volume. It gives an overview of the initiatives discussed in the volume, presenting the most important aspects pointed out by specialists working in such diverse fields as education, psychology, environmental research, nature conservation, environmental policy, financial sphere and law.

Keywords Institutions, Plastic, Policies, Pollution, Society, Stakeholders

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1 Introduction

The complexity of the plastic pollution problem and the urgent need to combine efforts of all stakeholders in the broad sense have led to the idea to divide the book project "Plastics in the Aquatic Environment" into two volumes: "Plastics in the Aquatic Environment – Part I: Current Status and Challenges" and "Plastics in the Aquatic Environment – Part II: Stakeholders' Role against Pollution". This second volume considers plastic pollution from the societal and policy points of view, which is a valuable addition to the more scientific character of the first volume, in which the chapters discuss sampling methods, sample preparation, analysis, monitoring studies and risks and consequences for organisms. These discussions have also been shown within the context of several specific countries. The current book volume "Plastics in the Aquatic Environment – Part II: Stakeholders' Role against Pollution" has 12 chapters that give an overview of various tools from diverse fields aiming at preventing or reducing plastic pollution. Such fields include environmental research and policy, nature conservation, psychology, education, finance and law. The authors come from a large variety of research organizations and agencies, including University of Plymouth (UK), University of Vienna (Austria), International Association for Danube Research (Austria), International Waste Platform, Institute for Nature Conservation of Vojvodina Province (Serbia), Institute for European Environmental Policy, University of Cadiz (Spain), European Commission – Joint Research Centre, Environment Agency Austria, German Environment Agency, International Commission for the Protection of the Rhine, HELCOM (Baltic Marine Environment Protection Commission), National Research Council (Water Research Institute, Italy), The Ocean Foundation (USA) and a few other universities and companies.

Such an extensive and diverse pool of authors allowed for, as we hope, a successful attempt to collect, in one book volume, different practices and actions aimed at tackling the plastic pollution issue. This range of instruments presented in this volume is in no way exhaustive as it only reflects a small portion of approaches. Moreover, discussion of all the existing programs in a single book would not be feasible. However, the aim of this book volume was to present some examples of plastics-related policy and law, financial mechanisms, educational programs and initiatives, and research on psychological factors which affect our attitude toward the plastic pollution problem. Even this small scope of examples presented in this book volume confirms the idea that plastic pollution should be addressed with an integrated approach which should be set up by combined efforts from all the stakeholders involved. Such steps should include change in human behaviour as we are the ones making decisions what products to buy, how to use them and how to dispose them; a wide range of formal and non-formal educational programmes and campaigns, involving all age groups; various bans, restrictions, laws and policies, as well as schemes and incentives; large-scale financial programmes; new advancements in the research and development area in the plastics industry. This all should be paired with the scientific community efforts on monitoring, analysis and

evaluation of plastics and microplastics both in the environment and living organisms including humans. Only such a comprehensive set of efforts can lead to the successful solving of the plastic pollution problem.

2 Overview of This Volume

Pahl et al. [1] highlight in their chapter how human perceptions and behaviour determine aquatic plastic pollution. They state that aquatic plastic pollution is entirely due to humans, because in the whole life cycle of plastic, specifically from production via consumption to disposal, the decisions by humans and their behaviour cause appearance of plastic in aquatic environments. All sectors and all individuals play a role in this process. For instance, manufacturers and designers decide on materials, functionality and appearance; buyers make purchases and dispose of products after their use; policy-makers make decisions regarding regulation. Many different groups in society feel strongly about the plastic pollution issue; there is no denial as concerning climate change. This offers the opportunity for change. At the same time, however, it is necessary to better understand how social perceptions and interactions are formed by media and NGO campaigns which are not always in line with scientific evidence. These programmes are strongly related to insights of behavioural science and thereby social and environmental psychology. They also should take into account key aspects that have been proven to be effective, such as empowerment, specific suggestions for behavioural solutions which are acceptable and feasible. Thereby individual behaviour as well as communities and bigger groups should be investigated taking into account social norms, social identities as well as other indications of behaviour change, thus exceeding a mere information/education focus. Intrinsic motivation and personal and social norms and values are of high importance. Top-down and bottom-up changes comprise individual change, actions by community, initiatives by industry (voluntary) as well as policy regulations. When these processes accompany each other, a reduction of plastic pollution in our aquatic environments could be obtained.

The chapter by Sandu et al. [2] about the role of society for reducing plastic pollution showed that stakeholders can still strengthen their cooperation with regard to a circular economy. Moreover, the authors mention a possible contribution of research, innovation, education and awareness raising. Sandu et al. suggest several measures to reduce plastic pollution by changing daily habits. They can be implemented on a personal level such as reducing (single-use plastics), reusing, recycling appropriately and repairing/sharing plastics. Moreover, each one can contribute to diminution of plastics by choosing products which are easier to recycle, shopping at the local level without packaging, buying fewer products with microplastics, purchasing alternative products (natural materials) or biodegradable products and participate in clean-up actions.

Another chapter, by Olga and Elena Mironenko, deals with different educational programs worldwide addressing plastic pollution via formal and non-formal

initiatives [3]. The diversity of involved stakeholders in formal educational programs in primary and secondary schools shows the interest towards environmental protection and the direct application of the obtained knowledge (e.g. recycling). Non-formal educational programs however reach a wider audience as more diverse formats can be used. However, the authors still see a lack of waste education and sustainability in educational programs and stakeholder collaboration. Moreover, the authors observe that stakeholders do not collaborate enough with government, that funding is often challenging and that mental models should be more addressed (individual choices).

The example of stakeholder analysis of protected areas along the Danube River in Serbia [4] shows that prevention and sustainable plastic management are still not enough established. Especially stakeholders play an important role for education and awareness raising with regard to conservation of protected areas and to water resources management. In their study, Kicošev and Galambos surveyed the willingness of visitors to pay for the preservation of natural environments. The results reveal that individuals would contribute if they benefit and if ecosystem services are used more frequently. The authors suggest to integrate payments for ecosystem services and protection of natural environments into national legislation and regulations. Moreover, this fund should finance clean-ups of these environments.

The chapter by Gionfra et al. [5] about the role of policy in tackling plastic waste in the aquatic environment deals with EU legislations and policy instruments in different countries. The increased attention towards plastics has led to many new regulations, market-based instruments, voluntary commitments and investments. A focus of the EU has been set on recycling although prevention and reuse would address the problem directly at its source. Although many measures have been implemented, improvements are necessary for reaching higher sustainability and circularity principles. The authors state that policy instruments often reveal weaknesses and that a diversification of measures could be more effective. A very important aspect is a change at the design stage as this could strongly influence the life cycle of products and probably lead to a reduction of plastic leakages. Moreover, the authors mention that extended producer responsibilities with regard to packaging can still be extended.

In the framework of the European Marine Strategy Framework Directive (MSFD) and the four related Regional Sea Conventions (OSPAR Commission, HELCOM, Black Sea Commission and UNEP/MAP Barcelona Convention), monitoring approaches for marine litter in the European Sea basins are implemented. This is particularly challenging because the European seas represent a complex situation for environmental management. The reason for this is that a large number of EU and non-EU countries share semi-enclosed sea basins, and there are overlapping transnational frameworks for marine environmental protection. With the aim to overcome a lack of harmonization and the risk of doubling efforts in the assessment and monitoring of marine litter pollution, several cooperation initiatives have been introduced, e.g. the harmonization of methods for monitoring approaches. This process is led by the MSFD Technical Group Marine Litter (comprising scientific experts and representatives from the four Regional Sea Conventions) who has

provided monitoring approaches and methodological standards for many member states in this context. González-Fernández and Hanke [6] reviewed the monitoring elements currently used and found out that despite a high degree of common criteria/indicators, they reveal gaps in coverage and maturity of approaches. However, actions and roadmaps are carried out to remove these gaps with the help of cooperation agreements.

In the chapter "Plastics in the Austrian stretch of the Danube River – From environmental data to action plans at the local, national and international level" [7], Hohenblum and Maier describe how a case study on the presence of plastics in the Austrian stretch of the Danube River led to several activities at the national and international level. In the same context they demonstrate the role of public entities and their cooperation (Ministry, Environment Agency, provincial Governments) and responsibility in dealing with environmental data for the comprehensive assessment of situations and evaluation of the efficiency of measures taken. For instance, a 10-point action plan to combat plastic pollution (example Danube River), issued by the Austrian Ministry for the Environment demonstrates actions at local, national and EU levels. Notably, the voluntary agreement with industry features actions which go beyond legal obligations triggered by a public entity. It has been shown that transferring national experiences onto the international level, for example, by gathering various stakeholders at conferences, is successful. The best illustration to this is the creation of the Interest Group Plastics of the EPA Network that connects positions and national experiences with the aim to affirm the EU Plastics Strategy [8]. Solving the issue of environmental plastics, and specifically marine litter, requires a determined commitment of all stakeholders. Moreover, both legal and voluntary measures are essential in order to tackle the problem at regional, national and global levels.

Several chapters in this book volume underline the role of rivers transporting to the seas. It seems obvious that plastic contamination of rivers is an important issue for river basin commissions. However, as Stötter and Schulte-Wülwer-Leidig from the International Commission for the Protection of the Rhine (ICPR) [9] state, the member states may have different views on the urgency of the issue according to their spatial location along the river basin. On the one hand, the states in the upper area of the river basin might find relatively low concentrations of plastics and therefore estimate its impact on water quality as relatively low, for example, compared to pesticides. On the other hand, some states in the lower parts have to face higher plastic concentrations and thus have action plans against it, which happens especially for marine areas. As there are currently no methods for regular monitoring, the ICPR has focused so far on collecting information from scientific studies carried out in the Rhine catchment and on information exchange among the member countries and the public. Principally, the ICPR could play an active role at different levels and with various directions including methodology (such as, for instance, information exchange of experts and possible harmonization), monitoring, public relations (for example, internationally coordinated clean-up campaigns or flyers) and measures (such as workshops and recommendations). Nevertheless, according to Stötter and Schulte-Wülwer-Leidig, it is vital that the relevant sectors

take as much action as possible to hinder more plastics from ending up in the aquatic environment.

In their chapter Ruiz and Stankiewicz [10] are dealing with the steps taken forward since the 2013 HELCOM Ministerial Declaration has been adopted. At that time, HELCOM agreed on considerably reducing marine litter by 2025, in comparison to 2015, and thus to protect the coastal and marine environment. Ruiz and Stankiewicz take a closer look at whether (1) there are suitable monitoring programmes present for various aquatic compartments, (2) there are enough monitoring data to evaluate tendencies, (3) the main sources of marine litter in the Baltic Sea are known and whether (4) there are regional actions planned related to sources in the frame of the HELCOM Regional Action Plan on Marine Litter (2015). The authors conclude that 2021 will be crucial for the HELCOM calendar, as this is the year when the Baltic Sea Action Plan (BSAP) will be updated. The BSAP which was signed in 2007 has navigated all HELCOM work to reach the goal of achieving the good environmental status of the Baltic Sea by 2021. The authors conclude that the latest scientific research should be used to amend actions so that the corresponding marine and water related targets of the 2030 Agenda for Sustainable Development can be fulfilled for the Baltic Sea. Moreover, this is needed for the achievement of the HELCOM's strategic goals and ecological objectives. The updated BSAP shall contain the existing commitments that may not be achieved by 2021 and it shall also consider new issues related to the commitments of the 2018 Ministerial Declaration and consultations during the BSAP update process.

Operational support for marine plastics source countries is essential in order to tackle the marine plastics issue at scale. As Caspary [11] describes in his chapter "Combating marine plastics: the role of finance and technical assistance by Development Finance Institutions" (DFIs), DFIs can play an important role in this, due to their considerable experience in assisting developing and emerging economies in solving various development issues. However, there are still some challenges in the way of DFIs trying to help render the marine plastics agenda effective. Caspary highlights two: the importance of country ownership and integration with other issue areas. As to the first one, the level of importance of the marine plastics issue to recipient countries (big marine plastics "source countries") will largely determine the effectiveness of the fight against marine plastics. Most DFIs shall undertake ambitious programs only if partner countries declare that this issue area is a priority. If such "source countries" do this, DFIs play an essential role by providing DFIs' finance and technical assistance. The second challenge is interlinked with the awareness of the overall significance of the plastics issue, understanding that it is in source countries' direct interest to act against it, and formation of connections with other important development issues. For instance, this latter point could include incorporation of the marine plastics agenda into new integrated solid waste management (ISWM) approaches that are widely supported because of their developmental effects. First, it is community-based recycling that reduces impact of uncontrolled plastics and creates jobs. Second, it is assessment on health risks from marine plastics, such as plastic contamination of the food chain or plastics blocking sanitary or storm sewage systems. Third, it is additional benefits for other

aspects of the environmental agenda, such as in instances when ISWM programs address methane emissions from waste.

The book chapter by Lara et al. [12] about plastic pollution and the legislative framework in Mexico shows that many challenges still exist. Jurisdictional responsibilities are unclear or overlap each other, plastics should be better reused and it should be prevented to enter the waterways by (1) abolishing production of not absolutely necessary plastics, (2) conducting clean-ups and more recycling and (3) creating an extended producer responsibility for producers. As laws differ between the states, the authors suggest to create a federal law which would be consistent throughout the country. Moreover, the authors suggest a more intensive collaboration between the government and industries.

In the chapter "The problem of microplastics and regulatory strategies in Italy" by Campanale et al. [13] the authors point out that on the national level, Italy has already implemented several mechanisms against plastic pollution and is the first country in the world to forbid by 2020 production and sale of care products and cosmetics with microplastics. It was also the first one to prohibit marketing and manufacture of non-biodegradable cotton buds from 1 January, 2019. Despite the fact that 70–95% of marine litter come from land, research in general is more focused on marine habitats rather than freshwater systems. Inland waters and rivers, however, serve as transport pathways to marine habitats and therefore should not be neglected as they can be a significant component of the global microplastic life cycle. In this context, Campanale et al. introduce the MICROPLASMA (MIcro and maCRO PLAStic pollution Monitoring with Advanced technologies) project that shall set up an integrated and innovative monitoring system along the Ofanto river in Southern Italy and that shall focus on spatial and seasonal trends of plastic wastes. Both climatic features climatic features such as river regime, storm and rain events and seasonality as well as human activities such as industrial wastewater, runoff from agricultural land, and treated wastewater effluent discharges considerably impact concentration of microplastics in freshwater environments. Temporal variability is especially important to define and to help identifying main drivers of microplastics. The authors point out that many samples are needed for determining daily variations (for example, associated with domestic waste), seasonal variability (mostly related to climatic factors) and year-to-year trends (mostly caused by human influence). Moreover, there is a need to increase the number of sample replicates to reduce spatial variability as high spatial heterogeneity of microplastic distribution in freshwater media suggests that only a portion of this heterogeneity could be caught in a sample. Sample replicates shall then be used to assess a spatially averaged value to determine mean values of microplastic concentrations.

3 Discussion

This book volume clearly shows that engaging education workers, society at large and policy-makers is very important for solving the plastic pollution problem. From the societal point of view, suggestions have been made here that stakeholders should

improve their cooperation. Moreover, research and innovation, education and awareness raising could also contribute to reduction of plastic pollution while an effort should be done by everyone to change daily habits.

Several gaps have been identified. For example, sustainable plastic management and prevention should be more emphasized. Although many different initiatives exist, educational programs still lack collaboration with governments. Moreover, waste education should be more targeted with regard to industry. It is obvious that the issue of plastic pollution in the aquatic environment is very complex. We cannot eliminate plastics altogether from our life as in many contexts the use of plastics has benefited the humanity. However, there are many unnecessary single-use plastics which can be easily banned or their use can be restricted and thus inflow of such plastics into the aquatic environment would ideally be considerably reduced or stopped. Such single-use plastics include straws and stirrers, plastic cutlery, lids and cups, plastic shopping bags or food containers. Development of alternative materials in order to reduce the use of plastics in certain products is under way. An advanced uptake of recycling, adoption of the circular economy principles can certainly not only reduce the volume of plastics in the environment, but also contribute to the creation of new jobs. As this book volume has shown, policy mechanisms, financial tools and international and regional institutions can help promote instruments to efficiently reduce the plastic problem at a large scale. At the same time, plastics enter the aquatic environment from land, and human behaviour plays a significant role in the amount of plastics that in the end reaches seas and oceans. Therefore, raising awareness regarding plastic pollution is of key importance. There are many ways to do so, for various age groups, contexts, at various knowledge levels, ranging from talks to schoolchildren and arranging clean-ups with children and students to giving lectures to the general public, organizing educational trips, engaging non-scientists in citizen science projects and running campaigns and programmes to collect litter working with divers, surfers, fishermen, cruise tourists, etc. There are plenty of opportunities that have already shown their efficacy but they would be even more efficient if all of the above can be implemented combined. At the same time, although there are ways to collect marine litter from water, it seems obvious that this effort is much more difficult than preventing plastics from entering the aquatic environment in the first place. Surely we need to continue arranging coastal clean-ups and removing litter from the water where and when such opportunity arises, but we also need to use such events to draw the public's and authorities' attention to the problem, to show that there are ways to change our consumer behaviour and use of plastics in many instances that will significantly reduce the inflow of plastics in the water. Furthermore, the recycling avenue provides inspiration and opportunities for development and a hope that plastics, where possible, will have a second life rather than end up in the aquatic environment.

Therefore, we hope that this book volume has provided our reader with a snapshot of an ocean of tools existing to tackle this problem that they will get inspired and become positive that the situation with the aquatic plastic pollution can be effectively improved in the near future.

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