



Case studies of macro- and microplastics pollution in coastal waters and rivers: Is there a solution with new removal technologies and policy actions?



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ABSTRACT

This opinion paper on microplastics pollution has selected different aspects and case studies of micro and macroplastic litter pollution in coastal waters, and rivers. We point out a discussion on this topic and ask ourselves if there is a solution to the global problem by developing new microplastics removal technologies as well as policy actions. The first two case studies are related with macroplastics marine litter in beaches, a third report describes a new simple sampling device for microplastics in coastal and nearshore areas, five case study assess microplastics pollution in worldwide coastal environments, sediments and catchments (India, Mexico, Australia, Europe and the Nordic Sea). Finally, different technologies to remove microplastics are highlighted as well as policy solution are listed to tackle this global problem with coordinated actions. Case studies on affordable wastewater tertiary treatments and new drinking water filtration systems are emphasized.

1. Introduction to plastic pollution

Plastic pollution is nowadays a global and ubiquitous problem being detected everywhere: marine environment, sand beaches, wastewaters, surface waters, soils, sludges, sediments, biota, food and air. The word plastic comes from the Greek term *plastikos*, which means that it can remain shaped in various systems. Global plastic production hit approximately 348 million tonnes in 2017, being China the largest producer responsible of 27% of worldwide pollution. It is estimated that more than 8300 million tonnes of virgin plastic have been produced to date. Many consumers are not aware that plastic goods are usually made in petrochemical plants. According to the 2019 Centre for International Environmental Law Report, its production will contribute approximately to 850 million tons greenhouse emissions. Plastic is part of our daily life and worldwide we use 4 trillion plastic bags annually and 1 million plastic bottles every minute [1].

Plastics in the environment are classified according to their size, even though there are not consensus on the size limits yet [2,3]. Commonly, they are divided into macroplastics (with particles >2.5 cm), mesoplastics (with particles 2.5 cm-5mm), microplastics (MPs) (with particles between micron- 5 mm) and nanoplastics (with particles between 1 and 100 nm) but there is an ongoing debate on the upper and lower limits of

these groups and the interval indicated here is only indicative and may change at the discretion of individual scientists. Macroplastic items—such as plastic bags, bottles discarded fishing nets, plastic toys, etc—are major components of marine litter visible in beaches, sea beads or floating that slowly break down into smaller fragments [4]. MPs are often not easily identifiable to the naked eye in the environment, particularly when mixed with sediment.

Macroplastics enter the marine environment via rivers, poor waste management or being dumped into the marine waters. MPs are directly released into the water or formed by degradation of macroplastics. In short, annually between 4 and 12 millions of tonnes of plastics are going into the oceans and most probably in 2050 MPs will exceed the amount of fish. The amount of anthropogenic debris in the marine and coastal environments is steadily increasing with an estimation of 270,000 plastics floating. In consequence international organizations, as well as non-governmental organizations (NGOs) recognize marine litter as a global issue of major concern. Plastic litter enters the marine environment from both, point and diffuse sources, and can be transported across rivers over long distances before being deposited on the bottom of seas. Few studies suggest that river litter can contribute up to 40% of all marine litter input, being estimated over 1.2–2.5 million tonnes of plastic every year [5,6].

MPs, are made from many different molecules and correspond to various product types. MPs are composed of diverse suite of polymer

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Abbreviations

DAF	dissolved air flotation
DFDS	microscreen filtration with disc filters
EGC	East Greenland current
GCS	Greenland sea gyre
HDPE	high density polyethylene
LDPE	low density polyethylene
MBR	membrane biological reactor
MP	microplastic
NGO	non-governmental organization
PA	polyamide
PE	polyethylene
PET	polyethylenephterephthalate
PP	polypropylene
PS	polystyrene
PVC	polyvinylchloride
RSF	rapid sand filter
SUP	single use plastics
UAS	unmanned aerial system
WWTP	wastewater treatment plant

type, being the most produced and consumed ones polypropylene (PP), low density polyethylene (LDPE), high density polyethylene (HDPE), polyvinyl chloride (PVC), polyurethane, polyethylene terephthalate (PET), polystyrene (PS) and polyamide (PA) are diverse and come from a multitude of sources, also they are in different sizes, colours, shapes and types of materials. MPs contain additives, i.e. phthalates and they can be as well a vector of organic contaminants and pathogens that can be ingested by organisms and introduced into the food web. Airborne fibrous MPs may enter our respiratory system with risk to the environment and humans [2,3,7].

Few case studies around the globe will reported showing the ubiquitous problems for macro and microplastic pollution in coastal and nearshore areas as well as in river waters and sediments. The selection criteria has been to choose recent studies that cover as much as possible the five continents reporting new finding that fill the existing gaps of knowledge. Furthermore, in addition, potential solutions to reduce the presence of plastics in the environment, with a special emphasis on the latest scientific contributions are also outlined.

2. Macro and MPs in coastal and nearshore areas

Although the increasing danger of plastic litter in the sea is an unquestionable reality, one of the gaps that still exist is the implementation of appropriate systems for monitoring and sampling. Up to the moment, it is based on in-situ visual census, which require human effort and are time-demanding. There is a need to develop new tools, specially mapping strategies to improve monitoring of marine litter on the coast.

Interestingly, drones were used for mapping marine litter [8]. Also known as unmanned aerial system (UAS) being a cost-effective aerial platform for autonomous collection of images with high spatial resolution. This UAS-marine based litter mapping was applied to a beach-dune system in Portugal. Photogrammetry, geomorphology, machine learning and hydrodynamics modelling were applied to process UAS images. Results obtained indicated that major marine litter loads within the monitoring beach-dune system were related to beach slope and water level dynamics on the beach profiles. This UAS device will give a lot of support to scientists, engineers and decision makers involved in marine and coastal pollution.

Another problem that remains to be solved is the lack of standardization in the sampling of MPs at sea. Traditional systems, such as

research vessels or small boats, are not useful in all cases and are hampered by numerous limitations in the near-shore area, ranging from too shallow (and risky) depths to the presence of swimmers. A new sampling device attached to a paddle board to acquire samples in the nearshore was recently presented [9]. This project was developed in the frame of a citizen science monitoring project with the non-governmental organization (NGO) Surfrider Foundation Europe. Also to mention, almost all material for this low cost, homemade paddle trawl can be bought in conventional hardware stores.

Authors also made a comparison with offshore data obtained with a standard manta trawl that shows differences in plastic size distributions, with MPs dominating offshore waters and larger pieces prevailing in nearshore waters. Concentrations of floating MPs found in the nearshore Barcelona are of the same order of magnitude than those found offshore in the Catalan Coast, with average of 10×10^4 items/km². Generally floating MPs dominate offshore, but greater proportions of mesoplastics and macroplastics dominate at the nearshore waters. In short, offshore waters receive. MPs from nearshore waters after degradation. This is an indication that nearshore waters are a source of plastic fragments to the open sea.

There is an urgent need for harmonized monitoring protocols that ensure the comparability of the results. In this sense, findings of beach litter surveys carried out by 7 NGOs in 23 sites along the Mediterranean coastline were recently reported [10]. To our knowledge, it is one of the first collective efforts of NGOs to obtain in a comprehensive and harmonized way baseline information on macroplastic marine litter in Mediterranean beaches. Five countries were involved: Croatia, Cyprus, France, Greece and Italy. The majority of litter items are plastics accounting for 90% of all litter detected. Single Use Plastics (SUPs) accounted for 38% of the recorded items. Average litter density was estimated in 451 items/100 m. Such large amount of SUPs found in beaches pushes the urgency of implementing measures to address this problem effectively. Hopefully, the SUP Directive approved in Europe last year will have a bigger impact in the coming years. Marine litter is certainly an example of a ubiquitous problem that does not have a one solution fits all; it requires a coordination of multiple stakeholders and multi-sectorial efforts across nations and disciplines in order to address it effectively including change of our current lifestyle.

In order to better understand the distribution and fate of MP pollution in coastal environments, MPs pollution and characteristics were assessed in coastal waters, beach sediments and marine fish in India [11], Abundances reported varied between of 1–2 particles/m³ and 40–70 particles/m³ in coastal waters and beach sediments, respectively polyethylene (PE) and PP were the dominant polymers. Additionally, the metal content of these MPs in beach sediments was reported for different MPs type for the first time in the Indian coast. This study also showed that plastic debris is a potential source of toxic metals in aquatic organism and the food chain in the marine environment. Cd and Pb were the most common metals in PE of beach sediments. MPs contamination was attributed to urbanization, river runoff, fishery and tourism activities as well as offshore transport.

The last case study reported here corresponds to the recent investigation of the abundance and distribution of MPs in the surface waters of the Nordic Sea [12]. It has been selected here because it is a particular case of MP pollution under extreme cold conditions. The Nordic Sea has three sea areas: Greenland Sea, Iceland sea and Norwegian Sea and possess several currents, including Greenland Sea Gyre (GSG). MPs abundance in the East Greenland Current (EGC) was 1.1 item/L being fiber, transparent and small MPs the most common t types present but the MPs in cold basin affected by GSG was higher, 2.5 items/L. MPs in GSG showed higher homogeneity of size, shape and colour. GSG increased MP pollution in the sea water as compared to other ocean currents. This work certainly will help to understand better the fate and relationship between MP and ocean currents and provides basic data for future MP research in the polar ocean.

3. Macro and MPs in river waters and sediments

Although the presence of MPs in rivers, lakes and other surface water bodies is well documented, information on the amount of MPs entering the sea by this route is still scarce and the partial contributions of the different sources and routes of plastics are not well established yet.

In this sense, the impacts of MPs from wastewater treatment plants (WWTP) and river into Todos Santos Bay in Mexico were recently reported [13]. This bay is connected to the Pacific Ocean and reports MPs sources and distribution in surface waters and sediments of this bay. This is the first integrated study of this kind in Mexico. MPs levels in surface waters were below 1 plastic-particle/m³, being fragments and fibers the most abundant particles. MPs varied from 85 to 2494 particles/m² in sediment samples. The range of MPs in WWTP effluents varied from 80 to 1556 particles/m³ being fibers the most abundant. The main synthetic polymers were PE, PP, nylon, PET and cellophanes.

Australia is another part of the globe where MP research achieved relevant outcomes. This provides a systematic investigation of MP pollution in Brisbane river sediments [14]. Although a lot of information was published on MPs not much is known about a tidal river systems, specially in sediments. PE, PA and PP were the three main polymer types found in Brisbane River sediments, MPs were classified in different categories according to their sizes: <1 mm, 1–2 mm, 2–3 mm, 3–4 mm and 4–5 mm. MPs less than 3 mm accounted for the highest proportion of PE, and PP particles. Smaller particles have higher probability of being mistakenly ingested by organisms. In addition, those that also have relatively lower density have increased potential for transport by wind and water as well. Due to the adsorption properties, plastic debris can be linked to biofouling and pollutants accumulation. As a consequence MPs can potentially contribute to the bio-invasion by acting as rafting materials leading to alien species invasion of an aquatic ecosystem.

Distance-based dynamic processes of MPs in river sediments suggest that not all plastic pollution generated from a river catchment is transferred to the ocean, with a proportion likely to be deposited in benthic or shoreline sediments, in the slow-moving parts of the river. Basically, the authors conclude that sediments act as sink of MPs and that there is a distance-based distribution of MPs hotspots in river sediments.

From the papers selected we already know that rivers are carriers of MPs pollution towards the sea. Following previous works in India, Mexico and Australia, this work reports a European case study [15] that reports seasonal MPs variations in nival and pluvial stretches of the river Rhine – from the Swiss catchment towards the North Sea over four seasons 2016–17. MPs concentration (>0.3 mm) correlated positively with average water discharge and catchment size of the evaluated stream locations. MPs concentrations were significantly higher in the downstream pluvial than upstream nival sites. This study also corroborates theoretical models that predict higher MPs loads downstream the river during the European winter months. In this respect, it has been assumed that the largest flux of MPs from the river Rhine towards the North Sea occurs between November and May, as predicted by transport and fate models. However, below-surface and mid-water column investigations are still required to establish a comprehensive flux prediction of transport and fate models. Another European case study corresponds to a recently published paper on riverine anthropogenic litter discharged in the Mediterranean Sea by the Besos and Llobregat rivers [16]. Based on European methodologies using visual observations for monitoring the floating litter during one year, from October 2016–September 2017, a total amount of 0.4 and 0.6 tonnes of plastic litter per year were estimated to be loaded into the Mediterranean Sea by both Spanish rivers.

All this information helps us to point out the magnitude of macro and MPs problem as well as the lack of knowledge on the real quantity of these pollutants that reach the sea from the surface waters. It is hoped that in the near future, continuous monitoring and efforts made to model behaviour will allow us to know exactly how intense this transport is.

4. Mitigation measures to decrease macro and MPs pollution

Although the problem of MPs is alarming, the optimistic and hopeful point of view is put forward by the various legislative, social and scientific initiatives that are being developed both to reduce the use of MPs by making consumption more responsible and to eliminate them from water once MPs have reached it. In this sense, many countries including the European Union agreed to ban primary MPs and more widely used disposable plastics (cotton swabs, cutlery, plates, straws, drink shakers and plastic balloon sticks in particular) and encourage the control marine litter [4,17]. Another important point is the social involvement in the elimination of MPs. Recently, the UN proposed 20 measures to follow by individuals that can help reduce pollution from plastics and MPs. Consumption decrease and recycling are the fundamental pillars [7,18].

Nowadays, a number of ongoing initiatives involving manual removal of marine debris from coastal and aquatic environment led by either, scientific communities or non-governmental organizations, are helping to eliminate the marine litter [17]. Programs that involved the incentive to bring science to society in order to eliminate plastics and MPs already polluting the environment already reinforce these initiatives. In this sense, initiatives like the already mentioned NGO Surfider Foundation Europe have a successful horizon [9]. Other initiatives focus on assessment, reduction, prevention and management of marine debris are also incentivized by regional, national and international authorities (e.g. of international ones are the United Nations Environment Program/Mediterranean Action Plan, the Oslo/Paris Convention) [17]. These initiatives, to be effective in the long term, need the implementation of circular economy systems (reduce, recycle, recover) that diminish the waste generated. Otherwise, they will become unviable over time.

To implement this concept of responsibility against plastic pollution, research & innovation especially within the plastics industry proposes an elegant addition — bioplastics for replacing conventional plastics (many of them more biodegradable) [18]. However, the biodegradation endpoint is problematic to define and delimit. Biodegradation effectivity depends on very specific conditions that are difficult to achieve in the environment and consequently, bioplastics can also yield MPs with the same effect as MPs derived from conventional materials but there is still a great lack of knowledge in this field. A pioneering study on this topic [19] performed a simple degradation experiment and found that poly-hydroxyalkanoate films formed MPs in water environment alike other biodegradable and conventional plastics. This study also highlighted the lack of knowledge on disintegration and degradation time of MPs of bioplastics, persistence, and their interaction and effects on aquatic biota. We expect that in a near future, a number of studies fill the knowledge gaps identified on bioplastics.

Many studies demonstrated that current water treatments eliminate a percentage of MPs presents in water [7,18,20–27], but also an important part of these studies recommend to add additional treatments to intensify MPs removal. Table 1 summarizes traditional treatments, new technologies that are already in place and those under investigation for wastewater and drinking water.

The presence and fate of MPs in wastewater is a topic of major concern, as wastewater is one of the main inputs of MPs to the environment. The highest removal efficiency achieved in traditional wastewater treatments can reach 99%. However, not all WWTPs can achieve it. Most of the studies pointed out that traditional WWTP eliminated better the larger MP particles but an advanced treatment is still required in order to improve the removal efficiency of small-sized microplastics (<100 µm) [24,26]. WWTP are still described as the major source of MPs release [20,21,28]. The most important disadvantage of these advanced treatment are the effort need for their development and the economical cost. In spite of this, some of them, such as membrane treatments and filtrations are already in used. Other are under investigation but already have shown promising results.

Table 1

Summary of wastewater treatments to eliminate MPs from wastewater and drinking water.

WASTEWATER	DRINKING WATER
Traditional treatment	
<i>Primary treatment:</i> Sedimentation and flotation, surface skimming	Coagulation Sedimentation
<i>Secondary treatment:</i> Sedimentation and activate sludge (biological treatment) and clarification	Sand filtration Sedimentation
<i>Tertiary treatment:</i> Chlorination, Desinfection	
Existing advanced techniques	
<i>Membrane treatments:</i>	Electrocoagulation
Reverse osmosis	Magnetic extraction
Membrane biological reactor (MBR)	Membrane separation
<i>Filtration</i>	
Rapid sand filter (RSF)	
Dissolved air flotation (DAF)	
Microscreen filtration with disc filters (DFDS)	
<i>Coagulation:</i> Use of polymers on flotation	
Experimental techniques	
Dynamic membranes	
Photocatalysis	
Elimination with fats	
Constructed wetlands	

Furthermore, an identified gap in this point is that removal is accomplished by the transfer of MPs from water to sludge that is further released to the environment as organic amendment [21]. It is not easy to eliminate MPs from the sludge. Alternatives to these advanced treatments that overcome this problem are in the spotlight. A widely proposed economical solution is to take advantage of the low density of MPs and their affinity to fat to favor the microplastics elimination in the grease removal stage and to treat the grease separately for preventing large number of microplastics entering the waste sludge [26]. A more natural solution recently proposed deals with the ability of horizontal subsurface-flow constructed wetlands, as tertiary treatment, to reduce the MPs concentration of secondary effluents [29]. The global WWTP efficiency for MPs removal was 98%. MPs removal efficiency by CW was on average 88%, causing a significant reduction of the MPs concentration from 6.45 to 0.77 MP/L ($p > 0.05$). This study as an interesting benefit assessed the potential role of macroinvertebrates in the MPs distribution along the wetland. Macroinvertebrates can ingest a non-negligible quantity of MPs and then, could be a factor in the MPs distribution inside constructed wetlands.

Although several studies describe the presence of microplastics in drinking water, there are still very few studies on the effectiveness of the technology for their removal [28,30]. The elimination of MPs from water when its ultimate destination is human consumption still rely only on expensive operations that were developed for other purposes but that works limiting the amount of MPs in water, such as filtration with zeolites, carbon or nanomaterials. These systems have numerous technical problems such as, low flow rate, limiting sample volume capacity, clogging, biofouling as well as a high cost. Other more specific research on the MPs removal in drinking water treatment process is still insufficient. However, some interesting attempts have been recently reported mostly on the development of new materials for magnetic extraction. As an example, the introduction of magnetic nanoparticle composites based on ionic liquids to remove organic, inorganic, microbial, and MPs pollutants from water deserves attention [31] because it achieves efficient, often quantitative removal of several typical surface water pollutants together with easy removal of the particles using a permanent magnet. These systems could lead to new materials for water purification systems, with significant advantages over those already notified.

In addition to the implementation of new technological solutions, another field that has received attention to reduce the presence of plastics in recent years has been the microbiological degradation. Recently, Yuan et al. [32] summarized the recent literature regarding

the microbial-mediated degradation of MPs showing that it is marked by the types of microbes and the environmental factors (i.e., temperature, pH and strain activity). The authors concluded that many aspects of MPs microbial degradation —still in its infancy— need to be better understood but the development of functional microbial agents to achieve a reduction in MPs is necessary. Although not well developed yet, this alternative seems to be one of the most consistent and promising ways to effectively eliminate microplastics. We expect that in the near future, there will be both advances in knowledge to better understand the processes and biotechnological advances from the point of view of the viability of microbes.

5. Concluding remarks and policy solutions

We would like to point out again the importance of MP and macroplastics litter pollution at global scale. Most recent papers reported in these few cases studies show the importance of continental waters and watersheds as transfer of MPs into the marine environment. MPs and macro litter pollution is nowadays in the radar not only of the scientific community but also of the public, the so-called citizen science. Two of the papers of this selection reported the strong participation of NGOs. Citizen or participatory science initiative plays a relevant role in the case of MP pollution. Media coverage helps to push such initiatives being complementary to scientific approaches. Such synergistic combination of academia, the public as well as policy actions should help to mitigate MP and macroplastics litter pollution in the next coming years. It is important to note that there are still many gaps in knowledge and we do not know well how plastics and PMs are transported and distributed and in what quantity. However, all these programs together with the modelling will allow us to know it soon. Monitoring and sampling systems also need to be improved especially in coastal areas and all existing programs will help. Technological solutions are expected to improve in the near future. The detailed study of the strictly technological alternatives to the solution of this problem, show that they are not sufficient, and that in many cases they just transfer the problem of water to the generated sludge. More studies in these aspects are absolutely necessary, because although the number of publications is enormous, the gaps in knowledge are also enormous. Another solution that is expected to be developed and that could bring more definitive results is the degradation of PMs by microorganisms (fungi and bacteria). Many studies are being carried out, although the complexity of these studies means that progress in this field is slow. In this context, we would like to add few recommendations already reported few years but still valid today: (i) law and waste management strategies, such as exploring new removal technologies (ii) education, outreach and awareness, (iii) source identification and (iv) increasing monitoring by reporting additional case studies where showing the relevance of MP around the globe and further research lines like the development of bioplastics to replace SUPs in our daily life.

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