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Current perspectives on the remediation methods of marine plastic pollution: a review

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Abstract. Plastic debris represents a contemporary point of concern for the marine environment, being discharged into the ocean at an alarming scale. However, the quantity of waste that is found in the ocean is unknown. Where does this waste come from, and where does it end up are questions that scientists and researchers are still trying to accurately answer. The majority of plastic products that make their way into the ocean come mainly from human activities. Most of them land on beaches, and eventually find their way into the ocean, being washed away by waves and tides. To assess the impact of these pollutants that are found in the marine environment, it is necessary to determine the concentration of the chemicals accumulating in the biomass, and the effects they cause. There are numerous biological effects which lead to many obvious diseases in marine species. Also, these harmful effects determine changes in community structure, the modification of the habitat and local or complete extinction of many aquatic species. This review aims to lay out the present situation of the marine environment, and the effects of the pollution caused by industrialization and urbanization. Different types of remediation approaches have been discussed, such as physical remediation techniques. Besides that, the role of numerous bacteria and fungi that are capable of breaking down these chemicals that surround us, has been highlighted and point at some of the bioremediation technologies that are currently available.

Keywords: plastic, pollution, marine environment, microorgansims, bioremediation.

Introduction

Taking into account the current situation in which the Planet is found, one can clearly observe the rapid degradation of the environment of marine organisms due to the massive pollution of the oceans. This matter has profound implications, both ecological and ethical, as well as economic and medical (Iñiguez *et al.*, 2016). The global marine ecosystem is at risk, including its major biodiversity and its unique realm. Ever since humans became a global driving force, constantly growing, and demanding for industrialization and globalization, natural environments such as the high seas have been deeply disturbed (Alava, 2019). Marine litter is considered to be any type of manufactured or processed material that is discarded or abandoned and that persists for a long time in the environment (Iñiguez *et al.*, 2016). The debris that is most commonly found in the marine environment is represented by glass, paper, plastic, and metal. Besides these, chemical waste and oil spills are also worth being mentioned and taken into consideration when addressing the rising concern regarding the pollution and therefore, the destruction of the marine environment. Plastic represents the main pollutant on our Planet; more than 380 million tonnes of plastic is annually produced, which eventually ends up in the ocean. The rate of total plastic waste reaching the ocean is about 3% (Jambeck *et al.*, 2015). There are two categories of plastic: macroplastic – plastic with the diameter larger than 0.5 cm, and microplastic – particles smaller than 0.5 cm (Lebreton *et al.*, 2019). Macroplastics are synthetic materials that last for a long time in the environment, which can be physically broken down into smaller pieces (microplastics), under the influence of sun rays and solar radiation (Moore, 2008). This review aims to present a clear image of the current situation regarding ocean plastic pollution and the measures that are used at the moment to reduce the ongoing harm. Even though different approaches have been described and applied so far, these including physical, chemical and biological methods, each one of them still has its limitations. Therefore, we aim to present their advantages and disadvantages, and also bring new perspectives on the remediation methods that are currently employed.

The amount of plastic waste that reaches the oceans

Plastic accounts for about 80% – 85% of marine litter; this percentage is increasing annually, as a result of the rising global consumption (Auta *et al.*, 2017). Based on the *National Oceanic and Atmospheric Administration* (Lippiatt *et al.*, 2013), at least 24 types of macroplastics have been determined, that currently float on the surface of the oceans. These are mainly represented by bags (for shopping and garbage), followed by food wrappers, disposable bottles (water and soft drinks), bottle caps, cleaning products packaging, personal care products, toys, toothbrushes, etc. (Lippiatt *et al.*, 2013). Different items were discovered per transect, around 217 macroplastics, where 1.15 m^{-2} and 91 of these being represented by food packaging. Unsurprisingly, the highest volume was taken up by empty bottles (Lippiatt *et al*., 2013). The large majority of macroplastics (around 82 million tonnes), originates from land regions, mostly beaches. Most of them come from the last 15 years; still, a substantial amount is older, showing that plastic can persist for several decades without degrading (Lebreton *et al*., 2019). A well-known hypothesis is that the macroplastic is continuously fragmented under the action of physical (eg. sunlight), chemical and biological (microorganism) factors into smaller pieces, called microplastic (Lusher *et al*., 2014; Reisser *et al*., 2015). The microplastic is coming from two main sources: the primary microplastics are those that are manufactured specifically for industrial applications and domestic products, such as cosmetics, cleaning products, pharmaceuticals, or resin pellets used in the plastics industry; the secondary ones are formed following the decomposition of macroplastics (Solomon and Palanisami, 2016; Sharma and Chatterjee, 2017; Lu *et al*., 2019).

Ocean's most affected areas

The Pacific Ocean Pollution

In oceans, massive circular current systems accumulate plastic waste in garbage *islands* at significant distances from land. In the northern part of the Pacific Ocean, in the midst of circular currents, such an island accumulates– the Great Pacific Garbage Patch (GPGP), which is reported to be a solid, continental form, entirely made of garbage. GPGP is one of the largest offshore plastic accumulation zones and is estimated to be bigger than Texas, possibly twice the size of the southern US's state (Lebreton *et al*., 2018). This Pacific trash vortex is made up of the Western Garbage Island, located near Japan and the Eastern Garbage Island, located between the states of Hawaii and California. The amount of debris within the GPGP accumulates because of the persistence of the pollutants in the environment and its reduced biodegradation capability (Morét-Ferguson *et al*., 2010; Philp, 2013). Researchers have shown that there are inter annual and seasonal variations in that specific location (Chen *et al*., 2018).

In 2001, the team of researchers led by oceanographer Moore C. found that in some areas of the patch, the concentration of plastic had already reached one million particles km^{-2}. Thus, there is a quantity of 335.000 pieces of plastic km^{-2} with an average weight of 5 kg km^{-2} (Ryan *et al*., 2009). Specific characteristics of the GPGP suggest that only certain types of plastic have the ability to persist on the surface of the ocean for a long time, accumulating and forming plastic patches in the ocean. It is known that plastic pollution is growing exponentially in the Pacific trash vortex, and at a much faster rate than in the surrounding waters, which means that the mass inflow is significantly higher than the outflow. The mass of plastics floating on the surface of the oceans is mostly mega- and macroplastic, and it is difficult to estimate how long it takes for them to degrade into smaller pieces, eventually disappearing from the surface of the water by sinking in the ocean (Lebreton *et al*., 2018). The existence of macroplastics that date back to the 70s, 80s and 90s, compared to more recent samples, suggests that some specific types of plastic (with a high volume-surface ratio, and in the presence of low wind) persist and accumulate in the GPGP (Brandon *et al*., 2016).

The Atlantic Ocean

The Atlantic Ocean is probably the second most polluted ocean after the Pacific, consisting of two main areas where the debris is accumulating (Morét-Ferguson *et al*., 2010). These are located in the North Atlantic Ocean, as well as in the South Atlantic Ocean, being represented by garbage patches that are similar to the GPGP (Lusher *et al*., 2014). It comprises different types of plastics that vary in size and form, such as the ones found in the GPGP (Lusher *et al*., 2014). Researcher Wilcox C. and his team have shown that the amount of plastic in the North Atlantic Ocean is growing over time, estimating that in 2010 alone it increased by 506,000 tonnes. They also suggested the fact that the abundance of garbage increases in the ocean due to the development of the industry and the never-ending use of plastic (Wilcox *et al*., 2019).

At the opposite pole, the garbage patch from the South Atlantic Ocean is located between South America and southern Africa (Ryan, 2014). Currently, it is considered that the South Atlantic Ocean garbage patch is substantially smaller, and more dispersed than the one in the North Atlantic Ocean since it is located between two continents that are still developing, and that have lower consumption rates. However, new studies claim that the eddies caused by ocean currents are interconnected globally, also stating that much of the waste will eventually end up in the GPGP (Van Sebille *et al*., 2012).

Causes and effects of plastic waste discharges into the oceans

This type of debris has a great impact on the marine environment, affecting the living organisms and causing their movement from one geographical area to another, where the living conditions are not optimal for them to thrive. Usually, these are represented by sessile and mobile organisms, including algae, invertebrates, fish, even iguanas, which have been observed floating on marine waste, becoming the main prey of plastic (Barboza *et al*., 2019). Over half of the macro items contain at least one hazardous component in their consistency. Macroplastic is the product of oil refining and its properties are enhanced using additives that are accountable for strengthening and softening the material.

Chemicals contained in plastic, like bisphenol-A and nonylphenol, are potential pests for the marine environment. These two additives are known to be harmful to the human endocrine system, which has led to the conclusion that they could have the same effects on several species. These chemicals disrupt the endocrine system by acting on estrogenic and androgenic hormones, thus stopping the development of organisms. It has been observed that macroplastics contain heavy metals, chemicals and pesticides, such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (Rios *et al*., 2010).

Marine and mangrove sediment have the ability to accumulate microplastics, these being considered to be settling tanks for these types of particles. Multiple studies have shown that microplastics can be bioaccumulated by the phytoplankton and ingested by the zooplankton and other organisms (invertebrates, fish, turtles, mammals), serving as vectors for the transport of pathogens, adsorbing and accumulating toxic substances (bisphenol A, ethers of polybrominated diphenyl, DDT) which can be subsequently transferred through the food chain (Solomon *et al*., 2016; Sharma and Chatterjee, 2017). Microplastics are easily accessible to a wide range of marine organisms due to their small size, often being confused with food and being ingested (Lu *et al*.,2019). However, there are also cases in which certain organisms target them. Several studies have shown that microplastics present a great health risk for the organisms that consume them, causing pathological stress, a false sensation of satiety, complications in the reproductive process, blockage of enzymatic processes, reducing growth rates and oxidative stress. Microplastics have the potential to cause cancer as well, lowering the immune response and causing malformations in animals, including humans. Consumption of microplastics can cause physical diseases, as well as chemical imbalances. The first developed as a follow up of the attachment of polymers to the surface externalities of the consumers, impeding mobility, and clogging the digestive tract. The latter includes inflammation, liver stress, accumulation of lipids in the liver and diminished development, thus, developing lipid and energetic metabolism disorders (Solomon *et al*., 2016; Auta *et al*., 2017; Sharma and Chatterjee, 2017; Lu *et al*., 2019). Once in the body, the microplastic can interact with the gut microbiota, causing several negative effects such as inflammation of the intestines and metabolism disorders. The microbiota and the immune system are connected; therefore, once the microbiota changes due to the accumulation of microplastics, various imbalances and diseases will be highly possible to develop in the host organism (Lu *et al*., 2019). Accumulation of microplastics can also take place through the ventilation process performed by the gills, microplastics being therefore bioaccumulated. These plastic particles endanger the life of fish, the mortality rate to those who have not yet reached maturity and have consumed plastic particles, growing considerably (Auta *et al*., 2017).

Remediation methods for macro- and microplastic pollution

Due to the exaggerated increase in plastic pollution, different countries have made huge efforts in order to develop innovative technologies that reduce, and have the potential to even overcome the enormous waste problem (Othman *et al*., 2020). When it comes to the remediation of plastic polluted areas, commonly used methods are the physical and the biological ones.

Physical methods

Considering the fact that we live in a world that is run by high technologies, it is surprising to see that, despite the horrifying environmental conditions, almost no robotic research has been run to expand a process that involves identification and collection of the waste materials, followed by its sorting, both at a macro- and micro-scale (Rojas, 2018). Another step that should be also taken into consideration is related to the possible sale of recycled plastic (van Giezen and Wiegmans, 2020). The few trash cleaning systems and robots that have been developed so far, can be categorized as static or dynamic systems (Fig.1). The first type, which is stationary, is divided into autonomous and mechanical systems, while the latter, that has the ability to move around, is either an autonomous system or a computational one. Besides these, there is also another alternative that integrates both systems. To put it more into context, when it comes to a static trash cleaning system, India and the US seem to be the leading parties. The Asian country developed a static-autonomous system that is environmentally friendly, being powered by solar energy. The marine debris is collected using a conveyor. The US, on the other hand, used the river's current energy, which is another environmentally friendly alternative to collect the floating trash. The system used fits into the static-mechanical category (Othman *et al*., 2020).

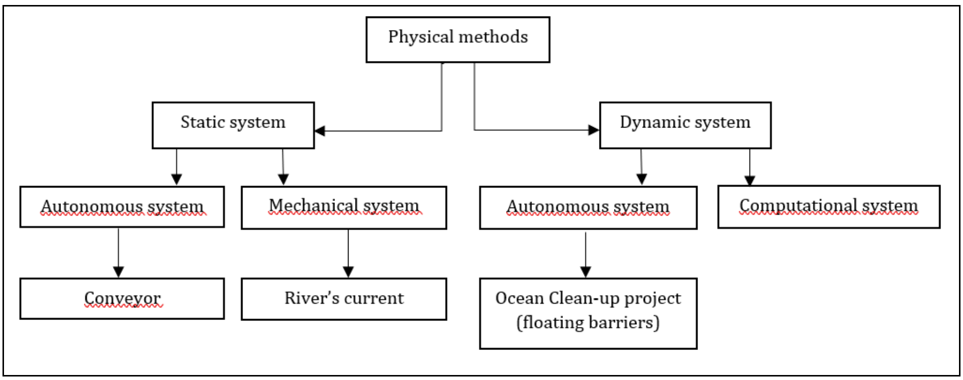

Figure 1. Physical methods for combating ocean plastic pollution.

When it comes to a dynamic-autonomous system, one of the most popular at the moment is The Ocean Cleanup project, which dates back to 2013. This system is currently deployed in the Pacific Ocean, where the greatest garbage patch is found (Slat, 2014; Hohn *et al.*, 2020). One of its main goals is to clean the ocean, while also protecting the environment, and its marine organisms, so that none of the wildlife could turn into a bycatch. Besides that, a well-thought design would include a low carbon-footprint of all the steps taken, from the construction to the supply chain processes (van Giezen and Wiegmans, 2020). The Ocean Cleanup project set the goal to clean the GPGP in the upcoming 20 years. Despite their high hopes, researchers such as Hohn and his team came to the conclusion that the surface plastic found in the entire ocean will be reduced by only 0.09% of the total amount by 2150. Following their model, even if deploying multiple cleaning systems into the oceans (around 200), the plastic debris would still be reduced by only 5,21% by 2150 (44,900 Mg of plastic out of 860,000 Mg). Their assessment took into consideration that the cleaning system assumingly works without failure, and that the plastic is homogeneous distributed (Hohn *et al.*, 2020). The system consists of an array of booms (floating barriers) and platforms. These are moored to the ocean floor and are able to capture the floating plastic particles, while marine organisms that are neutral remain underneath the boom, in the water flow. Turning this concept into reality, buoyant plastic can be efficiently removed from the seawater, following three phases. In the initial phase, plastic particles and pellets are trapped in the frontal area of the floating barriers. These come from the main flow of the ocean, and end up into the almost still water, located in the front of the barriers. Following the second phase, plastic particles and fragments accumulate, moving along the boom, following the path towards the platform. At the same time, new plastic waste is being continuously retained into the stream. In the final stage, the plastic flow that comes from both sides of the system meets in a central area, in front of the collection platform. Due to the increased concentration of debris, an efficient collection of floating plastics is possible (Slat, 2014). When it comes to dynamic-computational systems, the technology is not so advanced; therefore, these do not operate great garbage patches. Most of them are used to clean areas closer to the shore such as rivers, deltas, or seaports. Examples of such systems are Buddy catamaran (UK), Trash skimmers (US), Trash robot (US), etc. (Othman *et al*., 2020).

Considering the fact that The Ocean Cleanup project is among the most discussed at present, being also the only one that aims to operate on such a large scale, it is worth to be presented more in-depth, focusing on the advantages, disadvantages, opportunities, and threats that are associated with it. The Ocean Cleanup proposes the first large-scale marine plastic removal project *in situ*

(Morrison *et al*., 2019). The concept is based on passive cleaning, ocean currents favouring the accumulation of plastic around certain areas of the platform, subsequently being collected. However, the system does not work in line with initial expectations at the moment, as much of the waste is not retained, and does not reach the collection points. There are also concerns about how these platforms affect marine life due to the size of the equipment, and the lack of accurate data regarding the species that live in the North Pacific Ocean. Although the organization claims the fact that the wildlife is not affected, a survey conducted by experts in marine biology reports a major concern about the possibility of marine animals being affected or even dying as a result of their interaction with the platform equipment. One of the main concerns was regarding neustons, that thrive on the surface of the water (Helm, 2019). Thus, compared to other plastic removal alternatives, The Ocean Cleanup project possesses a potential danger to marine wildlife. Microplastics, as well as plastic debris that reached the ocean floor, cannot be caught by The Ocean Cleanup system. Besides that, the system cannot be considered as an approach that aims to reduce the enormous production of plastic, being only a post-consumer intervention, compared to various campaigns and projects that aim to prevent the use of plastic (Morrison *et al*., 2019). Even though there are drawbacks, the CEO and founder of the Ocean Cleanup project, Slat and his team are constantly improving the system based on the results that they get, following the multiple tests employed in the past years, concluding that an accurate ocean clean up is a complex process which involves years of work and assessments (Slat, 2018). However, the citizens participate in clean-ups and surprinsingly they can create immediate results and permanent changes in their local areas. These should serve as catalysts for major changes in people's behaviour and also encourage adoption of practices that can have a great effect on the remediation of the problem (Kiernan, 2009). Education is very important to reduce plastic waste and excesive pollution. This can change people's attitude and knowledge toward plastic waste and its management. There are also information campaigns that support and promote this type of education, such as The Ocean Cleanup project (Chow *et al*., 2017).

Beach cleanup represents a key approach used to reduce the marine and coastal environment pollution, such as plastic pollution. For example, Ocean Conservancy, organizes international coastal cleanups, as well as waterway and ocean cleanups every year involving many volunteers. However, it is impossible to identify how to organize them best and where and when to carry them out because the effects of these beach cleanups are not quantitatively well understood (Kataoka, 2015). It must be noted that the process of cleaning beaches requires good management methods, funds and adequate human resources (Krelling *et al*., 2017). This process may be done using specialized machinery such as sand cleaning machines that rake or sift the sand, or other chemicals such as oil dispersants (Frampton, 2010). Beach cleaning may be done by civic organizations, professional companies, the military or volunteers such as the Marine Conservation Society. There are two types of beach cleaning: mechanical and manual. Mechanical cleaning is defined as the removal of organic material or litter, which relies on the work of automatic or push machineries that rake or sieve the superficial layer of sand (Zielinski *et al*., 2019). Manual cleaning involves individuals picking up litter exclusively by hand. The combined use of manual and mechanical cleaning represents an approach which is effective and environmentally sound (Stelling-Wood *et al*., 2016).

Biological methods (bioremediation)

Bioremediation is a greener solution in comparison to the traditional physical and chemical approaches, being a cost-effective method, that is less destructive for the environment (Fig.2) (Adzigbli *et al*., 2018; Baniasadi and Mousavi, 2018; Junusmin *et al*., 2019). The microbial degradation of organic compounds is a biochemical process that implies the uptake of polymers. These polymers are referred to as degradation products that are processed by living microorganisms (MO). MO such as fungi and bacteria are involved in the degradation of the regular, synthetic plastic, as well as of the bioplastic. MO can degrade plastic differently depending on the area that the material is found. Plastic is split in nature aerobically, while the one present in landfills and sediments undergoes an anaerobic degradation, plastic in soil and compost being degraded partly aerobically (Ishigaki *et al*., 2004). Aerobic degradation, also known as aerobic respiration, is one of the most important factors in the decrease of contaminants in hazardous waste sites. The oxygen is used by aerobic MO as an acceptor electron. The MO break down organic substances into components with smaller molecular mass (Priyanka, 2011). Anaerobic biodegradation is the decomposition of organic compounds in the absence of oxygen. Some anaerobic bacteria use sulphate, manganese, nitrate, iron and CO_2 as their electron acceptors, to break down organic chemicals into smaller compounds. MO are not able to carry polymers directly through their external membrane to the cell organelles where most of the cell's biochemical processes take place, as long as the molecular mass of the polymer is large, and has no solubility in contact with water. In order for them to use carbon as an energy source, MO have developed a strategy in which they remove extracellular enzymes that cause the depolarization and decomposition of polymers, to be transported inside the cell (Gu, 2003). Also, the biodegradation of polymers to occur, MO must attach to the surface of polymers, eventually developing and growing by degrading the polymer, and using it as a source of carbon. MO can attach to the surface of polymers as long as the membrane is hydrophilic. During primary degradation, enzymes secreted by the organisms cause the main chain to split, leading to the formation of fragments with a low molecular mass, such as oligomers, dimers or monomers. These compounds with a low molecular mass are still used by MO as a source of carbon (Premraj and Doble, 2005).

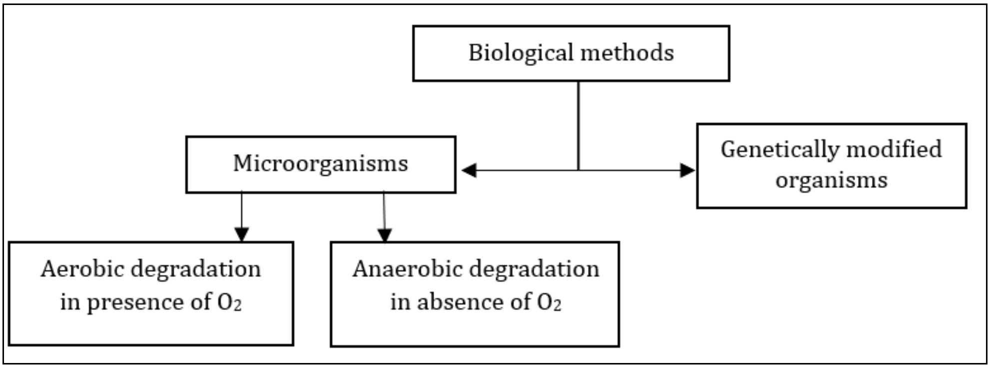

Figure 2. Degradation of ocean plastic using biological methods.

Using MO in the process of natural degradation of plastic has the advantage that these are able to resist under various conditions, such as withstanding extremely high or extremely low temperatures, and thriving in oceans at different depths. So far, a number of studies have shown the potential of plastic degrading bacteria, such as some that are capable of carrying the process below 4°C. Still, the main problem is often the identification of isolated MO that can carry such processes to an end result (Cameron *et al*., 2012). However, plastic degradation by MO is a slow process, because of their natural adaptation, which takes a long time, and therefore, the disposal of plastic into the oceans becomes irreversible (Debroas *et al*., 2017).

Genetically modified organisms (GMOs) are able to remove different types of pollutants such as plastics from the environment and to reduce the toxicity of those elements as well (Saxena *et al*., 2020). Polyethylene terephthalate (PET) is a synthetic polymer that has an unprecedented resistance to degradation, lasting centuries in the ecosystem. Recent studies have led to the discovery of a new bacterium called *Ideonella sakaiensis* 201-F6, that has the ability to grow using PET as an energy and carbon source, by producing an enzyme called PETase. The resulted products from degadation reactions are mono(2-hydroxyethyl) terephthalic acid (MHET) as a primary product and a smaller amount of terephthalic acid (TPA) and bis(2-hydroxyethyl)-TPA. MHET is then converted into two monomers, ethylene glycol (EG) and TPA, by a second enzyme called MGETase. (Austin *et al*., 2018). Despite the low solubility and stability of the enzyme, scientists succeeded in producing an active extracellular *Is*PETase. The enzyme will be used to generate a new *E. coli* strain, capable of accumulation and degradation of PET in its culture medium (Seo *et al*., 2019). The discovery of an enzyme that can break down such a resistant substrate as PET and the fact that the process takes place in only a few days, which is significantly less than the time that is naturally required for the biodegradation, raises the hopes for future success in using GMOs for plastic biodegradation (Carrington, 2018). Besides bacteria, scientists study other organisms, such as mealworms – *Tenebrio molitor* or moths – *Galleria mellonella* to which they can improve possible plastic degradation abilities, through different genetic engineering techniques (Yang *et al.*, 2015).

GMOs are created through various genetic engineering techniques with the main purpose of significantly improving the degradation rate of plastics and other pollutants. Many of these techniques are currently known, and used either to improve the expression of the enzymes found in the natural MO that are responsible for biodegradation in the environment, or to create MO that have a specific and efficient degradation rate for only one type of pollutant, by inserting a gene of interest that accelerates their performance. The discovery of the genes and metabolic pathways involved in biodegradation offers the possibility of creating GMOs that have a faster and a more efficient degradation activity, do not produce secondary pollution, eliminate the need to transport the plastic waste and the damaged environment can easily recover once the pollutants are removed (Liu *et al*., 2019). The biggest issue associated with the use of GMOs for the biodegradation of pollutants is the horizontal gene transfer to other species present in the ecosystem. This is the main reason why these cannot be currently released in the natural environment (Saxena *et al*., 2020). At the moment, there are no clear laws regarding the use of GMOs in bioremediation schemes, and the acceptance of their use is very low, especially in Europe. Therefore, detailed studies are required to assess the risks, which is a time-consuming process and which may lead to results not as satisfying as expected. Many studies and research are required in order to prove the lack of long-term risk to the environment, so that GMOs could be eventually used outside the laboratory as well (Janssen and Stucki, 2020).

Legal regulation to prevent the plastic pollution in the ocean

For several years, the marine environment has been considered by some states as the ideal landfill for a different range of waste products. In this context, an international regulation regarding ocean dumping had to be put in place. A large number of instruments at regional, national and international levels have been adopted to tackle marine pollution problems. These instruments comprise regulations, conventions, action plans, agreements, strategies, guidelines and programs. They contain some management measures that may be either voluntary or compulsory. Firstly, a convention was signed in London on 13 November 1972 (Farnelli and Tanzi, 2017), the purpose of which was to prevent marine pollution by discharging waste or other materials that could endanger human health and cause major damage to living marine organisms that are considered to be valuable resources, or could harm in any way the legitimate use of the high seas. Based on this convention, the parties shall take all possible measures to prevent marine pollution (Birchenough and The Hague, 2020).

Third United Nations Conference

The third United Nations Conference on the *Law of the Sea* was adopted in 1982 and is considered to be a true *Constitution of the Oceans*. It is also one of the most important treaties in the field, because it codifies the international law of the sea, so that, with regard to aspects of marine pollution, Article 194 provides that states must take into account measures to prevent, reduce and control pollution of the marine environment from any cause, regardless of its origin. Moreover, Article 197 obliges states to cooperate at regional or global level, directly or through any competent international organizations, to develop international standards and practices that comply with the provisions of the convention, in order to protect and conserve the resources of the seas and oceans (Nordquist, 2011).

International Instruments

United Nations Convention on the Law of the Sea (UNCLOS)

The UNCLOS is one amongst the foremost important agreements associated with the employment of the oceans. It introduces a wide regime for the law of the ocean by managing aspects of the marine environment such as environmental control, research projects, geopolitical delimitations, technology, economic activities and also the regulation of debates referring to ocean matters (Roberts, 2006).

Council Directive 2007/71/EC

Regulations are imposed regarding waste from ships and boats, so as to stop it from being dumped over the edge. Therefore, the directive requires ship captains to dispose the waste in reception centers in European ports before leaving it. Offshore of the ships that have not unloaded their waste is also prohibited (Carpenter, 2017).

UNEP Regional Sea Programme

The UNEP Regional Sea Programme and the Global Programme of Action (GPA) started working together in 2003 on the development of a general Initiative on Marine Litter (UNEP, 2011). The main activities include: reviewing the status of marine pollution within the region, organizing meetings of experts on marine pollution and national authorities, preparing regional action plans for proper management of marine litter, and also participating in a clean-up day within the International Coastal Cleanup Campaign (Jeftic *et al.*,, 2009).

National instruments

US Marine Debris Program

The Marine Debris Program (MDP) is an important national program to analyze and solve the issues that stem from marine debris, so as to guard and conserve the nation's marine environment, natural resources, economy, industries and also the people. It offers a holistic approach to marine pollution, and was established by the Marine Debris Research, Prevention and Reduction Act of 2006 (MDRPRA) (Lippiatt *et al*., 2013). The MDP has sponsored a large number of programs, including Fishing for Energy, monitoring and assessment projects, international coastal clean-ups, and also collaborated with UNEP to provide technical assistance to some countries in the Caribbean region (Barry, 2010).

Regional instruments

EU Initiatives on Land-Based Waste Management

The EU incorporates a wide selection of initiatives on land-based waste management, which can have a major impact on the quantity of waste in the marine environment. As an example, the Packaging Waste Directive outlines a variety of requirements to scale back the impact of packaging waste in the environment. It contains provisions on the prevention of packaging waste, on the re-use of packaging, and on the recovery and recycling of packaging waste (Interwies *et al*., 2013).

EU Marine Strategy Framework Directive

A large number of initiatives exist to approach marine debris in the EU. Among them, perhaps the foremost relevant may be the Marine Strategy Framework Directive (MSFD), the environmental pillar of the EU Integrated Maritime Policy. This directive is actually an integral policy instrument for the protection of the ocean environment for the European Community, following an adaptive ecosystem-based, and integrated approach to the management of human activities (Galgani *et al*., 2013).

Other significant legislations to marine pollution could have an important impact on the volume of waste in the oceans. For instance, The Beaches Environmental Assessment and Coastal Health Act aims to scale back the chance of diseases to users of the coastal recreation waters (Assessment, 2000).

The summary description of regional, national and international instruments approaching marine pollution can be a representative image of some of the most relevant methods. Because of the absence of a universal nature act, the level of international regulation development concerning the marine pollution mostly from land-based sources depends especially on the level of regional legislation development, also as on national legal institutions associated with the regulation of seas and oceans area, river basin pollution, the use and therefore the disposal of waste. Currently, most of the coastal states have already adopted the most relevant legislation in order to control marine pollution from land.

Conclusions

As scientists, we must have a vital role in transparently describing the scale of environmental hazards and what should be done in order to prevent them. The global implications of plastic pollution, coupled with the effects of other pollutants, are distressing. The current influx of wastes to the coastal regions of the seas and oceans is damaging and has a detrimental effect on many marine species. Progressive and dynamic pollution of the aquatic ecosystems may lead to a tragic deterioration of a significant part of marine resources. Such a decline might not be reversed for a large number of generations and will have a profound and lasting impact on the future of humanity. International collaboration is required in order to clean up all types of debris on the ocean and to reduce the major source of ocean microplastics. Research is also required to develop different strategies for *in situ* biodegradation of macro- and microplastics. While today research offers reason for faith and hope, future research should determine whether microbial genes involved in plastics degradation have begun to expand in the marine environment. When pollution management operations are not sufficient to overcome impacts and reach reduction targets in a reasonable time, social mobilization is an important ally to engage and motivate the general public and stakeholders to implement pollution solutions through behavioural change, social learning, and community-based conservation actions. The main focus must be on converting the way we live more sustainable by adjusting our over-consumptive lifestyles, rather than a narrower focus on sustainable consumer choices. We must renovate the way we live instead of only tweaking the choices that we make.

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